NASA CR-112085

N72-25852

# DEVELOPMENT OF A COLLAPSIBLE REINFORCED CYLINDRICAL SPACE OBSERVATION WINDOW

By

ABDUL Q. KHAN

Prepared under Contract No. NASI-10076 by

UNIROYAL, INCORPORATED

Mishawaka, Indiana

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Langley Research Center
Langley Station
Hampton, Virginia

# FOREWORD

This report was prepared by the Engineered Systems Department of UNIROYAL, Inc., Mishawaka, Indiana, under NASA-LRC Contract NASI-10076.
The work was administered under the direction of Dr. Jerry G. Williams of the Structures Division, NASA-LRC, Langley Station, Hampton, Virginia.

The final report covers the work conducted during the period June 2, 1970 to December 31, 1971. Additionally, this report includes the summaries of the previous reports, NASA-CR-66299 and NASA-CR-66823 prepared under Contract NASI-5524 and NASI-7771, by the Engineered Systems Department of UNIROYAL, Inc., Mishawaka, Indiana.
This report was compiled and prepared by A. Q. Khan, under the direction and approval of Mr. R. C. Kohrn, Manager, Engineered Systems Department, with Mr. D. D. M. Streed as New Product Manager, Mr. G. E. Kelsheimer as Chief Consultant, and Mr. D. V. Dighe as Engineer.
Unfailing assistance was also rendered by Mrs. Becky S. deBruyn early in the material evaluation program and Mr. Edward A. Reske in the Phase II window fabrication program.
The author also wishes to acknowledge the assitance of Mr. Harry F. Kline and Mr. David L. Pippen of NASA-MSC for their assistance in scheduling the White Sands Test Facility for flammability and gas analysis work.

## TABLE OF CONTENTS


| | Page |
|---|---|
| FOREWORD | ii |
| LIST OF TABLES | vii |
| LIST OF FIGURES | x |
| LIST OF SYMBOLS AND CONVERSIONS | xiii |
| SUMMARY | 1 |
| INTRODUCTION | 2 |
| SUMMARY OF PRIOR ART | 4 |
| Selection of Optically Transparent Flexible Polymers | 5 |
| Reinforcement Material Evaluation and Selection for Two-dimensional Polymeric Sturctures | 6 |
| Evaluation of Reinforcement Patterns | 7 |
| Other Properties of Selected Polymers | 8 |
| Study for Development of an Improved Reinforced Flexible Window Panel | 9 |
| OBJECTIVE | 11 |
| TECHNICAL GUIDELINES | 12 |
| PHASE I PROGRAM | 14 |
| MATERIAL SELECTION FOR FLEXIBLE CYLINDRICAL WINDOWS | 15 |
| Transparent Matrix Polymer | 15 |
| Polymers Shielding Material | 16 |
| Effect of Aging on Window Composite Materials | 16 |
| FLAME RETARDANTS FOR OPTICALLY TRANSPARENT POLYMER | 18 |
| Requirements for a Flame Retardant | 18 |
| Selected Candidates for Flame Retardants | 18 |
| Evaluation of Flame Retardants in Conathane EN-1554 Films | 19 |

| | Page |
|---|---|
| FLAMMABILITY AND OFFGASSING EVALUATION OF WINDOW MATERIAL FILMS AND LAMINAE WITH AND WITHOUT FLAME RETARDANTS | 23 |
| Upward Combustion Rate Test | 23 |
| Odor Test | 25 |
| Carbon Monoxide, Total Organics and Flash and Fire Point Test Results | 25 |
| DTA and DGA Analysis | 27 |
| REINFORCEMENT SELECTION AND EVALUATION | 30 |
| REINFORCEMENT EMBEDMENT METHOD EVALUATION | 33 |
| Cast Film Applied to Mandrel and Spraying Techniques | 34 |
| Spin or Dip Casting | 36 |
| Vacuum Encapsulation | 37 |
| REINFORCEMENT ANGLE EVALUATION | 41 |
| Effect of Reinforcement Angle on Window Composite Strength and Window Fitting Attachment (Mathematical Analysis) | 41 |
| Reinforcement Angles Selected for Evaluation | 43 |
| Criteria for Reinforcement Angles Evaluation | 43 |
| FABRICATION OF REINFORCED CYLINDRICAL WINDOWS - PHASE I | 48 |
| Evaluation of Release Agents | 48 |
| Procedure for Subscale Window Fabrication | 49 |
| Mold Preparation | 49 |
| Vac-Trials | 50 |
| Application of Silicone (Sylgard 184) Film Barrier | 50 |
| FITTING ATTACHMENT SYSTEM FOR PHASE I WINDOWS | 52 |
| TESTING | |
| PHASE I - WINDOW TESTING PROCEDURE | 55 |

| | Page |
|---|---|
| PHASE I - WINDOW TESTING RESULTS | 55 |
| Dimensional Changes | 55 |
| Dimensional Changes Under Pressure | 55 |
| Dimensional Changes Due to Collapse/Extension Cycles | 56 |
| Optical Transparency | 61 |
| Evaluation Program | 61 |
| Human Factors Optical Test | 61 |
| Effect of Reinforcement Angles on Optical Transparency | 64 |
| Pressure Testing of Subscale Cylindrical Windows | 64 |
| Flex and Peel Bond Strength Tests | 73 |
| RESULTS OF REINFORCEMENT ANGLES EVALUATION | 75 |
| CONCLUSIONS FROM PHASE I - STUDY | 76 |
| PHASE II TASKS | 77 |
| PHASE II PROTOTYPE FABRICATION AND EVALUATION | 78 |
| Design Parameters | 78 |
| Window Composite Materials | 79 |
| Urethane Polymer Formulatipns for Vacuum Encapsulation | 80 |
| Urethane Film Casting | 81 |
| Dull Black Coating on Steel Wire Reinforcement | 82 |
| Netting Pattern Design Parameter | 83 |
| PHASE II TOOLING FOR WINDOW FABRICATION | 84 |
| PHASE II WINDOW FABRICATION PROCEDURE | 86 |
| Precast Film Application | 86 |
| Vacuum Encapsulation | 86 |
| Silicone Application | 87 |
| PHASE II WINDOW FITTING ATTACHMENT | 91 |

| | Page |
|---|---|
| PHASE II WINDOW TESTING | 96 |
| Pressure Testing before Collapse/Extension Cycles | 97 |
| Verification of Transparency | 97 |
| Collapsibility Test | 102 |
| Pressure Testing after 10 Cycles of Collapse/Extension and 24 Hours in Collapsed Condition | 109 |
| Blowout Strength | 109 |
| CONCLUSIONS | 111 |
| RECOMMENDATIONS | 113 |
| LIST OF MATERIAL SUPPLIERS | 114 |
| REFERENCES | 116 |
| APPENDIX | |
| A. Test Methods | 117 |
| B. Test Data | 124 |
| C. Light Transmittance Curves and Thermographs | 142 |

# LIST OF TABLES


| Table No. | Title | Page |
|---|---|---|
| I | Effect of Heat Aging on Percent Light Transmittance | 17 |
| II | Selected Flame Retardants for Urethane Polymer | 20 |
| III | Loss in Percent Light Transmittance at 556 mu After Heat Aging and Ultraviolet Exposure | 22 |
| IV | Window Materials Selected for Tests | 24 |
| V | Summary of Upward Flame Propagation Rate and Odor Tests | 26 |
| VI | Summary of Carbon Monoxide Total Organics and Flash/Fire Point Tests | 28 |
| VII | Summary of Thermograph Analysis | 29 |
| VIII | Reinforcement Material Parameters | 31 |
| IX | Summary of Reinforcement Embedment Methods Evaluation | 40 |
| X | Relationship Between Axial Reinforcement Angles and Tension in Flexible Window Wall Composite | 44 |
| XI | Cylindrical Windows Selected for Reinforcement Angle Evaluation | 47 |
| XII | Summary of Dimensional Changes Under Pressure | 57 |
| XIII | Eye Chart Characters Used in Human Factors Optical Test | 62 |
| XIV | Human Factors Optical Test Rating Plan Used in Cylindrical Windows | 62 |
| XV | Human Factors Optical Tests for Phase I Windows Containing Axial Wires at Angles | 67 |
| XVI | Pressure Tests for Phase I Subscale Flexible Cylindrical Windows | 70 |
| XVII | DeMattia Flex and Peel Bond Strength Test Results - Urethane Composite Only | 74 |
| XVIII | Phase II - Netting Pattern Design Parameter | 83 |
| XIX | Phase II - Human Factors Optical Test Results | 98 |

| Table No. | Title | Page |
|---|---|---|
| XX | Phase II - Window Visual Quality Evaluation | 104 |
| | APPENDIX B - DATA TABLES | |
| XXI | Phase I - Flame Retardant Evaluation in Urethane Polymer (Percent Light Transmittance After Heat Aging) | 125 |
| XXII | Phase I - Flame Retardant Evaluation in Urethane Polymer (Percent Light Transmittance After U.V. Exposure) | 126 |
| XXIII | Strength Test Data on Reinforcement Materials Used | 127 |
| XXIV-A | Combustion Rate Test for Conathane EN-1554 Film with 10% Fyrol FR-2 | 128 |
| XXIV-B | Combustion Rate Test for Conathane EN-1554 Film | 128 |
| XXIV-C | Combustion Rate Test for Sylgard 184 - Silicone Film | 129 |
| XXIV-D | Combustion Rate Test for Lamina: Sylgard 184/ Conathane EN-1554 with 10% Fyrol FR-2/Sylgard 184 | 129 |
| XXIV-E | Combustion Rate Test for Lamina: Sylgard 184/ Conathane 184/Conathane EN-1554/Sylgard 184 | 129 |
| XXV-A | Flash and Fire Point Temperature Test for Conathane EN-1554 Film with 10% Fyrol FR-2 | 130 |
| XXV-B | Flash and Fire Point Temperature Test for Conathane EN-1554 Film | 130 |
| XXV-C | Flash and Fire Point Temperature Test for Sylgard 184 - Silicone Film | 131 |
| XXV-D | Flash and Fire Point Temperature Test for Lamina: Sylgard 184/Conathane EN-1554 with 10% Fyrol FR-2/Sylgard 184 | 131 |
| XXV-E | Flash and Fire Point Temperature Test for Lamina: Sylgard 184/Conathane En-1554/ Sylgard 184 | 132 |
| XXVI-A | Odor Test for Conathane EN-1554 Film with 10% Fyrol FR-2 | 133 |
| XXVI-B | Odor Test for Conathane EN-1554 Film | 133 |
| XXVI-C | Odor Test for Sylgard 184 - Silicone Film | 133 |
| XXVI-D | Odor Test for Lamina: Sylgard 184/ Conathane EN-1554 Film with 10% Fyrol FR-2/Sylgard 184 | 134 |

| Table No. | Title | Page |
|---|---|---|
| XXVI-E | Odor Test for Lamina: Sylgard 184/ Conathane EN-1554/Sylgard 184 | 134 |
| XXVII-A | Carbon Monoxide and Total Organics Tests for Conathane EN-1554 Film with 10% Fyrol FR-2 | 135 |
| XXVII-B | Carbon Monoxide and Total Organics Tests for Conathane EN-1554 Film | 135 |
| XXVII-C | Carbon Monoxide and Total Organics Tests for Sylgard 184 - Silicone Film | 135 |
| XXVII-D | Carbon Monoxide and Total Organics Tests for Lamina: Sylgard 184/Conathane EN-1554 with 10% Fyrol FR-2/Sylgard 184 | 136 |
| XXVII-E | Carbon Monoxide and Total Organics Tests for Lamina: Sylgard 184/Conathane EN-1554/Sylgard 184 | 136 |
| XXVIII | Thermograph Analysis Data | 137 |
| XXIX | Dimensional Changes Under Pressure For Phase I Windows | 140 |
| XXX | Dimensional Changes and Material Degradation Due to Collapse/Extension Cycles for Phase I Windows | 141 |

## LIST OF FIGURES


| Figure No. | Title | Page |
|---|---|---|
| 1 | Plaster Mandrel for Cylindrical Window | 35 |
| 2 | Vac-Mold for Phase I Flexible Window Fabrication | 38 |
| 3A | Cylindrical Window with Reinforcement Members at Different Angles | 41 |
| 3B | Phase I - Cylindrical Window with Only Girth Reinforcement Members at An Angle | 42 |
| 3C | Angle Formed by Girth Reinforcement Members in Phase I Windows | 42 |
| 4 | Effect of Axial Reinforcement Angles on Window Reinforcement Tensions for 46.0 cm Diameter Cylindrical Window Under 40.8 nscm Pressure | 45 |
| 5 | Phase I - Window Fittings and Attachment System | 53 |
| 6 | Phase I - Window Before Collapsing | 58 |
| 7 | Phase I - Flexible Window in Collapsed State | 59 |
| 8 | Phase I - Flexible Window in Free-State After One Cycle of Collapse/Extension | 60 |
| 9 | Human Factors Eye Chart | 63 |
| 10 | Phase I - Flexible Window with Axial Reinforcement Members (R-1) at Zero Degree Angle | 65 |
| 11 | Phase I - Flexible Window with Axial Reinforcement Members (R-1) at 17 Degrees Angle | 65 |
| 12 | Phase I - Flexible Window with Human Factors Eye Chart Inside for Optical Transparency Test | 66 |
| 13 | Phase I - Flexible Window with No Internal Air Pressure | 71 |
| 14 | Phase I - Flexible Window Under 10.413 nscm Air Pressure | 72 |
| 15 | Phase II - Vac-Mold Design | 85 |
| 16 | Phase II - Fabrication System for Flexible Window Using Combination of Preapplied Film and Vacuum Encapsulation | 88 |

| Figure No. | Title | Page |
|---|---|---|
| 17 | Phase II - Sectional View of Vac-Mold Chamber After Casting Cylindrical Window | 89 |
| 18 | Phase II - Composite Wall Structure of a Typical Collapsible Observation Window | 90 |
| 19 | Phase II - Attachment System for Flexible Windows to Fittings | 94 |
| 20 | Phase II - Cylindrical Window Fittings Assembly | 95 |
| 21 | Phase II - Flexible Window with Black-Coated Steel Wire Cable Reinforcement, R-2 | 99 |
| 22 | Phase II - Flexible Window with Steel Wire Cable Reinforcement, R-2. Photograph Taken at a Distance of 100 cm from the Window Wall | 100 |
| 23 | Phase II - Flexible Window with Black-Coated Steel Wire Cable Reinforcement, R-2. Photograph Taken at a Distance of 200 cm from the Window Wall | 101 |
| 24 | Phase II - Flexible Window Pressure and Collapsibility Test Set Up | 103 |
| 25 | Phase II - Flexible Window # US.L-4 before Collapsibility Test | 105 |
| 26 | Phase II - Flexible Window # US.L-4 Collapsed to 15.3 cm in the First Cycle | 105 |
| 27 | Phase II - Flexible Window # US.L-4 after 3 Cycles of Collapse/Extension | 106 |
| 28 | Phase II - Flexible Window # US.L-4 Collapsed to 11.4 cm after Seven Cycles of Collapse/Extension | 106 |
| 29 | Phase II - Flexible Window # US.L-4 Collapsed to 10.0 cm after 10 Cycles of Collapse/Extension | 107 |
| 30 | Phase II - Flexible Window # US.L-4 Extension after 10 Cycles of Collapse/Extension | 107 |
| 31 | Phase II - Flexible Window # US.L-4 Collapsed to 10.0 cm Under Its Own Weight after 10 Cycles of Collapse/Extension and 24 Hours in Collapsed Condition | 108 |
| 32 | Phase II - Flexible Window # US.L-4 Extension After 10 Cycles of Collapse/Extension and 24 Hours in Collapsed Condition. Window Needed Support for Extension | 108 |

| Figure No. | Title | Page |
|---|---|---|
| 33 | Phase II - Flexible Window # US.L-4 Pressurized to 3.47 nscm after 10 Cycles of Collapse/Extension and 24 Hours in Collapsed Condition. Air Pressure Extended the Window Without Any Support. | 110 |
| 34 | DeMattia Flex Test Machine | 120 |

## LIST OF SYMBOLS AND CONVERSIONS USED IN TEXT

Symbols:

| | |
|---|---|
| mm | Millimeters |
| cm | Centimeters |
| n/cm | Newtons per linear centimeter |
| nscm | Newtons per square centimeter internal pressure |
| nts | Newtons tensile strength |
| $A^o$ | Angstroms |
| mu | Wavelengths in millimicrons |
| mg | Milligrams |
| ugm/gm | Micrograms per gram of sample material |
| Kg | Kilograms |
| n | Newtons |
| $Kg/cm^2$ | Kilograms per square centimeter at a given thickness |
| $\theta$ | Angle in degrees |
| u | Microns |
| U.V. | Ultraviolet |
| RTV | Room Temperature Vulcanizing |
| F.R. | Flame Retardant |

Conversions:

1 nscm = 1.44033 pounds per square inch

1 n/cm = 0.56668 pound per inch

1 mm = 0.03937 inch

1 nts = 0.2248 pound

1 Kg = 2.2046 pounds

1 ugm = $1 \times 10^{-6}$ gram

1 $A^{o}$ = $1 \times 10^{-8}$ cm = $3.937 \times 10^{-9}$ inch

1 u = $1 \times 10^{-4}$ cm = $3.937 \times 10^{-5}$ inch

1 mg = $1 \times 10^{-3}$ gram

1 mu = $1 \times 10^{-7}$ cm

1 $kg/m^2$ = 0.00142 pound (mass) per square inch at a given thickness

## SUMMARY

During the course of this contract, existing material technology was applied to the development of a collapsible transparent window suitable for manned spacecraft structures.

The effort reported herein encompasses the evaluation of flame retardants intended for use in the window matrix polymer, evaluation of reinforcement angle which would allow for a twisting pantographing motion as the cylindrical window is mechanically collapsed upon itself, and evaluation of several reinforcement embedment methods.

A fabrication technique was developed to produce a reinforced cylindrical space window of 45.7 cm diameter and 61.0 cm length. The basic technique involved the application of a clear film on a male-section mold; winding axial and girth reinforcements and vacuum casting the outer layer.

The high-strength transparent window composite consisted of a polyether urethane matrix reinforced with an orthogonal pattern of black-coated carbon steel wire cable. A thin film of RTV silicone rubber was applied to both surfaces of the urethane.

The flexible window models have successfully demonstrated the design transparency after several collapse/extension cycles and pressure tests.

A retraction system, fittings attachment mechanism, and closures to provide a positive airtight seal to the top and bottom of the flexible cylindrical window were also designed.

A system for attaching the flexible cylindrical window to rigid fittings was developed for installing the window in space structures.

# INTRODUCTION

Advanced manned space programs have indicated a requirement for visual observation of experiments and subsystems located exterior to the space structure.

To date, all spacecraft for manned space flight have contained windows which have proven extremely useful in conducting photographic-type experiments and in providing the capability for visual horizon and relative spacecraft referencing. Additionally, the psychological aspects of a window in a manned space structure have also contributed to the success of manned flight missions. A flexible window in the expandable lunar shelter would allow observation of shelter support equipment and lunar experiments by taking advantage of external illumination for lighting. Such a window could be inserted in an otherwise opaque expandable structure and provide increased operational safety for the crew.

Planners of future manned space missions involving space shuttles, space stations, further lunar explorations, and interplanetary flight have repeatedly established requirements for a flexible window. To demonstrate the technological feasibility of a flexible window concept, an investigation was conducted to determine if a flexible window, compatible with the space environment, could be developed for such applications. The need also existed to apply such technology to processes amenable to the construction of three-dimensional geometric bodies.

The investigation approach adopted during earlier work was to first screen available, flexible transparent polymers and reinforcement materials; second, to parametrically evaluate the reinforcement pattern; third, to develop the

technique of fabricating flexible two-dimensional and sections of three-dimensional geometric bodies; and last to test the resulting windows and their attachment system to space structures, in the simulated space environments.

Prior art mainly had been confined to the development of two-dimensional flexible windows, whereas the current efforts were directed toward developing methods for constructing three-dimensional windows, such as a cylindrical window. Such a collapsible cylindrical window would extend from the side of a space vehicle and would serve as a port to permit direct viewing of inaccessible areas.

## SUMMARY OF PRIOR ART

Early work (Ref. 1) mainly was confined to the evaluation and selection of a flexible transparent material which could become an integral part of the flexible wall of an expandable structure. Under NASA Contract No. NASI-5524 (Ref. 1), the conceptual study included the selection of transparent flexible polymer and reinforcement, reinforcement filament spacing and patterns; and fabrication and experimental evaluation of flat sheets and cylindrical sections constructed of judiciously selected materials. Testing of these flexible transparent materials was conducted in pressure loaded test fixtures. Their strength and optical characteristics were determined under loaded conditions. Finally, three scale model filament wound cylindrical chambers with hemispherical ends, each incorporating a flexible transparent window were designed and fabricated for further evaluations.

As the known flexible transparent polymeric materials alone did not possess sufficient strength to resist the pressure loads developed in a manned spacecraft structure, the approach taken to meet the strength and optical requirements was an open orthogonal reinforcement encapsulated in a flexible transparent matrix. Rectangular space areas between reinforcement groups were available for light transmission and viewing.

Initially, the guidelines for the window material were that it be capable of carrying a load of at least 1482 n/cm (840 lbs./in.) in the direction of maximum stress and exhibit good optical characteristics under a pressure differential of 4.86 nscm (7.0 psi). The blow-out strength of the window matrix was based on 4.86 nscm (7.0 psi) working pressure load with a safety factor of 5. Additionally, consideration was given, before final selection, to the material characteristics which resist hard vacuum, temperature extremes, micrometeoroids, and radiation (U.V. and particulate).

Under NASA Contract No. NASI-5524 (Ref. 1), the investigation approach taken to meet the guideline requirements was as follows:

PRIOR ART IN MATERIAL EVALUATION AND SELECTION FOR TWO-DIMENSIONAL STRUCTURES

A. Selection of Optically Transparent Flexible Polymers

Earlier work (Ref. 1) consisted of the evaluation of eight polymers out of four generic types of polymers for optical and mechanical properties. Where necessary, appropriate additives were incorporated into the polymers to improve the clarity, curing characteristics and physical properties.

The four generic types of polymers were:

1. Ethylene propylene copolymer and terpolymer
2. Millable and castable polyurethanes (polyester based)
3. Dimethyl RTV silicone
4. Polyisoprene

The materials were either cast or molded in sheets of various thickness. Transparency and strength tests were performed on the sheet materials before and after aging for one week at $212^{o}$ F and also for 240 hours in a Fadeometer with output strength of 3.15 watts/$m^2$ (33.9 watts/$ft^2$) of wavelength below 4000 $A^{o}$ (ASTM procedure D-750-55T).

The initial results were as follows:

1. Ethylene-propylene copolymer and polyisoprene materials both were unsatisfactory for the application due to their initiation of crazing, embrittlement, and reduced transparency, after heat exposure, and degradation due to U.V. radiation.
2. Slight crazing due to U.V. radiation was noticed in the polyester urethane, but the heat exposure darkened it.
3. The silicone polymer exhibited excellent resistance to both heat and ultraviolet exposure.

4. The percent of incident light transmitted by RTV silicone and polyester urethane in the visible spectrum ranging 4000 $^{o}$A to 7000 $^{o}$A was interesting. Silicone transmitted 93% of incident light throughout this range, whereas urethane was essentially opaque at 4000 $^{o}$A and increased to 88% at 7000 $^{o}$A.

5. Effect of silicone film thickness ranging from 0.094 cm (0.037 in.) to 0.434 cm (0.171 in.) on percent light transmission through the visible spectrum was negligible, but this was untrue for urethane. A decrease from 84 percent to 71 percent transmission was noticed at a particular wavelength of 575 $^{o}$A where urethane film thickness was increased from 0.122 cm to 0.338 cm.

6. To determine the ability of the matrix material to resist bending and repeated folding, during packaging, flex tests were conducted using a Bally flexometer instrument (Ref. 1). Both the polyester urethane and RTV silicone successfully completed 349,000 flex cycles without failure. One of the serious drawbacks in using silicone alone for fabricating a window was its notch sensivity and corresponding low tear strength; urethane comparatively was quite tough and resistant to tear propagation.

Exploring the test results obtained during the evaluation of optically transparent polymers indicated the possible use of silicone/urethane lamina in order to achieve the desirable properties of both materials. (Lamina concept was further advanced under NASA Contract NASI-7771 (Ref. 2).)

B. Reinforcement Material Evaluation and Selection for Two-dimension Polymeric Structures

Under NASA Contract No. NASI-5524 (Ref. 1), three different types of reinforcement candidates were evaluated, including eight glasses, one

steel, and one polyester filament. Each reinforcement material was molded into test samples 12.7 cm x 2.54 cm as uniformly spaced uniaxial strands. The tensile strength of the candidate reinforcement materials were measured before and after heat exposure (212$^{o}$ F for 7 days) using constant strain rate test machine (Ref. 1). Polyester filament was found unsatisfactory for the application as the test samples were distorted and wrinkled badly due to shrinkage and secondly, to obtain the required design strength of 1482 n/cm (840 lbs/in), in the girth direction, polyester fiber would fill the entire window viewing field.

Both the steel wire and 901-S fiberglass filaments appeared to be satisfactory for window reinforcement material. Further investigation in this area led to the use of steel wire in the window matrix.

C. Evaluation of Reinforcement Pattern

Initially, various spacings of filaments were evaluated to determine the effect of spacing on optical resolution both for nonstressed and pressure loaded conditions. Fifteen reinforcement pattern panels were evaluated. It was observed that if filaments were cast too close to the surface, local stress induced surface straining seriously affected resolution characteristics.

Light transmission tests conducted on the reinforced panels revealed that the presence of the filaments reduced the percent of incident light transmitted by approximately the percent of projected area taken up by the filament (from 10 to 30 percent, depending on the pattern and wavelength). Investigation in the area of reinforcement pattern was further carried out under NASA Contract No. NASI-7771 (Ref. 2) which indicated that those reinforcing patterns having the

larger open areas provide the better optical properties (12.7 mm x 12.7 mm and 6.35 mm x 6.35 mm vs. 3.175 mm x 3.175 mm and 1.587 mm x 1.587 mm). This was based upon the ability to focus through individual openings in the pattern. The most significant reason for changing to a large grid rests in the selection of a urethane matrix material possessing strength and adhesion capabilities far in excess of the silicone matrix used previously under Contract - NASI-5524 (Ref. 1).

The later selection of steel wire as a sole reinforcement material (Ref. 2 - Phase III) made it possible to fabricate a grid pattern having the minimal total thickness equal to two cable strands (0.6350 mm). This was possible by aligning the wire strands in a "ribbon" rather than "bunching" them as was inevitable with the fiberglass roving.

D. Other Properties of Selected Polymers

Since the flexible window had to retain pressure, the gas permeability of the composite materials (Ref. 1, 2) were also investigated. The permeability tests on silicone-fiberglass reinforced panels and unreinforced silicone and polyurethane panels were conducted in accordance with ASTM method D-1434-66. The permeability of the nonreinforced silicone and fiberglass reinforced silicone panels were of the same magnitude, indicating that the reinforcement had negligible effect on permeability. Heat exposure ($212^{o}$ F for 7 days) did not appreciably change the permeability of the two polymers. Dimethyl RTV silicone demonstrated lower permeability than Conathane EN-1554 (polyether based urethane evaluated and used exclusively under NASA Contract No. NASI-7771 (Ref. 2). However, the window construction consisting of polyether urethane sandwiched in between two layers of RTV silicone was most desirable, for window application, when considering both the strength and permeability requirements.

In conclusion, the study conducted under NASA Contract NASI-5524 (Ref. 2) established many parameters indicating that a flexible window matrix constructed of optically transparent polymer reinforced with wire was quite feasible for use in expandable space structures.

E. Study for Development of an Improved Reinforced Flexible Window Panel

The major objective of the work conducted under NASA Contract NASI-7771 (Ref. 2) was to develop an improved, flexible, transparent space window suitable for use in a flexible expandable space structure.

The work included the evaluation of seventeen polymers from three generically different types (polyurethanes, dimethyl silicones, and polybutyrals) as the potential matrix materials in the composite.

Two glass rovings (901-S with HTS finish and 1014-S types) and two steel filaments (0.1016 mm brass plated carbon rocket wire and 0.3175 mm brass plated carbon rocket wire cord having seven strands of 0.1016 mm brass plated wire) were evaluated as reinforcements in the window matrix.

Four basic reinforcement patterns were evaluated, and an adhesive means of installing windows in simulated space structure panels was developed and tested under a sustained pressure of 4.86 nscm for 24 hours.

Based upon the work conducted during the course of NASA Contract NASI-7771 (Ref. 2), the following conclusions were of major importance in the development of a cylindrical collapsible space observation window:

1. A polyether urethane matrix (Conathane EN-1554) provided the necessary transparency, strength, flexibility and bonding characteristics essential in the window composite.

2. The RTV silicone (Sylgard 184) when cast in a low gauge film, 0.254 mm to 0.381 mm, was capable of withstanding flexing which was not characteristic of the same material on higher gauge films.
3. The high strength steel filament provided a low gauge reinforcement pattern which permitted a thinner window composite.
4. A reinforcement pattern having larger open areas provided better optical properties. This was based upon the ability to focus through individual openings in the pattern.
5. A transparent flexible window appeared satisfactory for use in space vehicles if the window consisted of brass-plated carbon steel cable (as reinforcement) embedded in a matrix of castable polyether urethane, which in turn had a castable dimethyl RTV silicone laminated on both sides.
6. The urethane matrix encapsulated in the RTV dimethyl silicone does not exhibit the adverse effect (crazing and reduction in transparency), characteristics of the polyurethane, upon exposure to ultraviolet light.

Previous NASA contracts, NASI-5524 (Ref. 1) and NASI-7771 (Ref. 2), studies resulted in the development of a high strength composite exhibiting exceptional optical transparency and flexibility.

This initiation of the present contract was based upon the need to apply the technology developed under the previous two contracts (Ref. 1, 2) to processes amenable to the construction of three-dimensional geometric bodies, such as cylindrical windows, which could be located on the side of a manned spacecraft for conducting external experiments or activities.

## OBJECTIVE

The main objective of this contract effort was twofold:

(1) Develop a process (or processes) for the construction of cylindrical, collapsible transparent window geometries.

(2) Demonstrate this technology by the construction of a model of a collapsible observation window.

The above two objectives included the necessary investigations of fabrication techniques, conceptual and detail design of window attachment system, retraction system with cap and seals, and finally, conducting physical and mechanical tests on the models to demonstrate the flexible window concept.

## TECHNICAL GUIDELINES

The technical guidelines specified below were established to assist in formulating design parameters for cylindrical observation window:

1. The material is assumed to be exposed to the space environment including hard vacuum extremes, radiation (ultraviolet and particulate), micrometeoroids, and temperature extremes.
2. Materials are assumed to be exposed to mechanical damage such as sharp instrument scratching.
3. The window structure shall be as flexible as possible.
4. The flexible window structure shall be capable of being collapsed to at least one-sixth of its original length.
5. The ultimate strength goal for the flexible window structure shall be at least 829 n/cm (470 lbs/in.) in the direction of maximum stress.
6. The blowout strength of the window shall be based upon a 10.2 nscm (14.7 psig) pressure differential with a safety factor of 4, i.e., total pressure of 40.8 nscm (58.8 psig).
7. The transparent composite shall be designed to exhibit good optical characteristics under a pressure differential of 10.2 nscm (14.7 psig).
8. Fire retardants compatible with window composite materials shall be given consideration.
9. The maximum allowable level of carbon monoxide and total organics shall not exceed that established by NASA Report MSC-D-NA-0002 (Ref. 3).
10. The overall wall design thickness of the window shall be maintained at a maximum of 2.79 mm.

11. The window shall be assumed to be exposed to the space environmental conditions (item 1. above) for a period of one year.
12. Final cylindrical window model shall be of 45.7 cm diameter and 61.0 cm long.

## PHASE I PROGRAM

The tasks set forth in the Phase I program consisted of the selection of matrix polymers, reinforcement materials, reinforcement embedment methods evaluation, and reinforcement angle. The program also included the fabrication of optically transparent subscale cylindrical windows (15.2 cm diameter by 20.3 cm long) using the selected window parameters, and testing the subscale cylindrical windows for composite wall stress (equivalent to 40.8 nscm or 58.8 psig at burst in 45.7 cm diameter cylinder) and collapse/extension cycles.

At the end of the Phase I evaluation program, three subscale windows with fittings attached and equipped with one retraction system were sent to NASA for future evaluation.

## MATERIAL SELECTION FOR FLEXIBLE CYLINDRICAL WINDOWS

### A. Transparent Matrix Polymer

On the basis of conclusions from the previous related contract, NASI-7771 (Ref. 2), Conathane EN-1554 polyurethane was selected for the fabrication and evaluation of cylindrical observations windows. Conathane EN-1554 is a polyether based polyurethane resin system and has shown overall excellent performance characteristics for transparent windows. Major consideration for the selection of urethane candidates were: strength, flexibility, optical transparency, processibility, good tear resistance, and bonding characteristics. Although Conathane EN-1554 exhibited a substantial reduction in transparency after exposure to ultraviolet light for 240 hours, the urethane matrix encapsulated in the RTV silicone did not exhibit the adverse effect characteristics of polyurethane upon exposure to ultraviolet. With the existence of the degradation condition of urethane alone in ultraviolet light, the potential of a laminate construction having RTV dimethyl silicone as a shielding material was greatly enhanced.

### B. Polymer Shielding Material

Dimethyl RTV Sylgard 184 silicone was selected as an exterior "barrier" lamina for the window composite. Earlier works (Ref. 4) on the performance of elastomeric silicones in ablative and space environments had indicated that, generally, phenyl containing silicones have less resistance to UV radiation than dimethyl containing silicones. However, this is the opposite of the effect caused by particle radiation.

Deficiencies noted with Sylgard 184 are its inherent adhesion inadequacies and its notch sensitivity (low tear resistance), however, its

resistance to degradation by factors of the space environment, excellent optical properties and ease of processibility made Sylgard 184 a primary choice as a barrier film.

C. Effect of Aging on Window Composite Materials

The composite developed for constructing the window wall structure consisted of a three-layer laminate in which Sylgard 184 silicone formed a thin inner and outer layer and Conathane EN-1554 containing steel wire reinforcement formed the middle layer. Such a combination resulted in a synergistic improvement by taking advantage of desirable characteristics of both materials.

As the window was to be exposed to space environments, there was interest in the potential degradating effect of heat and ultraviolet on the window composite and its light transmittance. Table I shows the effect of aging on the nonreinforced window composite and its components.

Test results (Table I) revealed that Sylgard 184 exhibited a greater transmittance of light at all points along the spectrum than did Conathane EN-1554.

TABLE I

EFFECT OF HEAT AGING ON % LIGHT TRANSMITTANCE*

| Code No. | Material | Thickness of Film mm | Condition** | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Unaged | | | | | | | Aged 1 week 212° F | | | | | | | Aged 240 hours-U.V. | | | | | | |
| | | | 400 | 420 | 490 | 575 | 585 | 642 | 700 | 400 | 420 | 490 | 575 | 585 | 642 | 700 | 400 | 420 | 490 | 575 | 585 | 642 | 700 |
| | | | (mu) | | | | | | | (mu) | | | | | | | (mu) | | | | | | |
| S | Sylgard 184 | 2.42 | 93.0 | 94.7 | 95.7 | 94.7 | 94.6 | 94.5 | 94.5 | 88.3 | 90.0 | 91.7 | 91.6 | 92.0 | 92.0 | 91.5 | 75.0 | 79.7 | 87.5 | 90.0 | 90.5 | 91.7 | 92.3 |
| C | Conathane EN-1554 | 2.16 | 41.0 | 60.0 | 86.3 | 91.0 | 91.3 | 81.5 | 91.5 | 44.5 | 58.5 | 81.7 | 88.0 | 88.3 | 88.5 | 89.0 | 2.0 | 4.8 | 31.5 | 66.5 | 69.5 | 79.0 | 84.3 |
| S/C/S | Sylgard 184/ | 0.480 | | | | | | | | | | | | | | | | | | | | | |
| | Conathane EN-1554/ | 1.524 | 45.0 | 70.0 | 90.5 | 92.3 | 92.5 | 93.0 | 93.7 | 15.0 | 29.0 | 76.5 | 89.5 | 90.5 | 92.0 | 92.5 | 2.5 | 3.7 | 30.0 | 65.0 | 67.5 | 78.5 | 96.5 |
| | Sylgard 184 | 0.480 | | | | | | | | | | | | | | | | | | | | | |

*For test method, see Appendix A.

**For transmittance curves, see graph Nos. 1, 2 and 3 in Appendix C.

## FLAME RETARDANTS FOR OPTICALLY TRANSPARENT POLYMER (Conathane EN-1554)

### A. Requirements for a Flame Retardant

The history of the Space Program has demonstrated the need for control of flammability based not only on the elimination of known ignition sources, but also on control of propagation pattern and consequences of any fire which may occur. This required the design discipline in the selection and evaluation of various flame retardants for transparent polymers. Concerted efforts were made to make Conathane EN-1554 urethane polymer more fire resistant using additive type flame retardants. Major emphasis was placed on the following parameters in selecting the flame retardants for evaluation in Conathane EN-1554 polymer:

1. Compatibility of flame retardant with polyether urethane polymer.
2. Clarity of flame retardant in the matrix polymer.
3. Effectiveness of flame retardant in making matrix polymer flame resistant.
4. Resistance to any degradating effect after heat and ultraviolet exposure.
5. Liberation of any unacceptable level of carbon monoxide, total organics, and other offgassing.

### B. Selected Candidates for Flame Retardant

Five types of flame retardants were selected for evaluation in Conathane EN-1554 matrix polymer. All of the flame retardants were clear liquids which were mixed in the urethane polymer before casting films. Initial levels of flame retardants in the polymer (based on weight of Conathane parts A and B only) were 20%, 18%, 15% and 10%, but after two trials, two levels, namely, 20% and 18% were eliminated from further evaluation.

Major emphasis was placed on the evaluation of flame retardant at the 15% level, however, it was later reduced to the 10% level in order to minimize any degradating effect of flame retardant on light transmittance properties after aging and ultraviolet exposure.

Details of each flame retardant selected for evaluation are given in Table II.

C. Evaluation of Flame Retardants in Conathane EN-1554 Films

Each flame retardant mentioned in Table II was mixed in various proportions with liquid urethane polymer and their clear films were cast on glass plate (30 cm x 30 cm) having a precast surface of silicone film. At the same time, control films without flame retardant additive were cast on separate silicone film surface. Cast films were cured and subjected to heat aging at 212$^{o}$ F for one week and 240 hours at 125$^{o}$ F in ultraviolet (See test methods in Appendix A).

After heat aging and ultraviolet radiation exposure, those films containing Firemaster T23P at all levels became very dark and, therefore, it was not further evaluated. It was determined that Firemaster T23P contained bromine which was comparatively less stable than chlorine when subjected to space environments. No further attempts were made to evaluate flame retardant with bromine content. Conathane EN-1554 films containing Firemaster T33P at 15% and 10% levels, Fyrol CEF at 15% level, and Aroclor 1232 at 15% level showed relatively less discoloration on visual examinations and are further evaluated for percent light transmittance (See test method in Appendix A and percent light transmittance curves in Appendix C).

For screening purposes, the percent light transmittances were compared at the wavelength of 556 mu (maximum visibility in daylight or brilliant

TABLE II

SELECTED FLAME RETARDANTS FOR URETHANE POLYMER

| Code | Candidate | Chemical Nature | Per Cent | Source |
|---|---|---|---|---|
| 1F20<br>1F18<br>1F15 | Firemaster T23P | $BrCH_2CHBrCH_2O$<br>$BrCH_2CHBrCH_2O$ → P = O<br>$BrCH_2CHBrCH_2O$<br>Tris (2,3-dibromopropyl) phosphate | 20<br>18<br>15 | Michigan Chemical Corp. |
| 3F18<br>3F15<br>3F10 | Firemaster T33P | $(ClCH_2)_2CHO$<br>$(ClCH_2)_2CHO$ → P = O<br>$(ClCH_2)_2CHO$<br>Tris (1,3-dichloroisopropyl) phosphate | 18<br>15<br>10 | Michigan Chemical Corp. |
| 4F18<br>4F15 | Fyrol CEF | Tris (beta chloroethyl) phosphate | 18<br>15 | Stauffer Chemical Co. |
| 5F15 | Aroclor 1232 | Chloronated polyphenyls | 15 | Monsanto Co. |
| 6F10* | Fyrol FR-2 | Tris (dichloropropyl) phosphate | 10 | Stauffer Chemical Co. |

*Selected at a later stage of evaluation program.

artificial light is at 556 mu). The results are summarized in Table III. Percent light transmittance through the films with and without flame retardants were also compared at various wavelengths along the visible spectrum from 400 mu to 700 mu. The results are shown in Tables XXI and and XXII, Appendix B, and percent light transmittance curves (Graphs No. 4 through 9) in Appendix C.

Films containing "Aroclor 1232" as a flame retardant exhibited less discoloration and better light transmission, after aging for one week at 212$^{o}$ F, than the other flame retardants evaluated. After 240 hours exposure to UV, the films containing "Aroclor 1232" stiffened and developed surface crazing. "Aroclor 1232" was rejected from further consideration.

During the course of T33P flame retardant evaluation, another flame retardant, Fyrol FR-2, showed promising results. Visual examination showed very little surface crazing and stiffness after aging the films (containing 10% Fyrol FR-2). Additionally, film discoloration due to heat aging at 212$^{o}$ F for one week and UV exposure for 240 hours at 125$^{o}$ F was less in the films with 10% Fyrol FR-2 than films with 10% Firemaster T33P. For this reason, Fyrol FR-2 was used in the laminae and then tested for combustion rate (upward), flash and fire point, odor test, offgassing and total organics. Results of such tests are described in Tables IV through VII.

TABLE III

LOSS IN PERCENT LIGHT TRANSMITTANCE AT 556 MU
AFTER HEAT AGING AND ULTRAVIOLET EXPOSURE+

| Code No. | Flame Retardant % | Aged for 1 Week at 212° F | | | | | | | U. V. Exposure for 240 Hours at 125° F | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Unaged | | Aged | | | | | Unaged | | Aged | | | | |
| | | Thickness mm | % LT* | Thickness mm | % LT* | Loss in % LT | Diff. | Remark ** | Thickness mm | % LT* | Thickness mm | % LT* | Loss in % LT | Diff. | Remark ** |
| 3F15 | 15% Firemaster T33P | 2.387 | 84.5 | 2.362 | 42.5 | 49.7 | 10.4 | 4 | 2.337 | 84.5 | 2.311 | 43.5 | 48.5 | 3 | 3 |
| 3F0 | No Firemaster T33P | 2.692 | 83.0 | 2.286 | 55.0 | 39.3 | | 4 | 2.616 | 83.5 | 2.565 | 45.5 | 45.5 | | 4 |
| 4F15 | 15% Fyrol CEF | 2.464 | 84.0 | 2.311 | 32.0 | 61.9 | 29.0 | 1 | 2.489 | 83.5 | 2.337 | 47.5 | 43.1 | 0 | 1 |
| 4F0 | No Fyrol CEF | 2.438 | 83.5 | 2.438 | 56.0 | 32.9 | | 4 | 2.515 | 83.5 | 2.489 | 47.5 | 43.1 | | 3 |
| 5F15 | 15% Aroclor 1232 | 2.185 | 79.0 | 2.235 | 42.0 | 46.8 | 3.9 | 1 | 2.261 | 78.0 | 2.159 | 45.0 | 42.3 | 2.8 | 1 |
| 5F0 | No Aroclor 1232 | 2.489 | 73.5 | 2.540 | 41.5 | 42.9 | | 4 | 2.438 | 73.5 | 2.413 | 44.5 | 39.5 | | 3 |

* % L.T. Per cent light transmittance

** 1 Film surface crazed and stiff
2 Film surface crazed
3 Slightly film surface crazed and stiff
4 Slight film surface craze on folding
5 No craze or stiffness as compared to control films

+ See Graphs # 4 through 9, Appendix C.

## FLAMMABILITY AND OFFGASSING EVALUATION OF WINDOW MATERIAL FILMS AND LAMINAE WITH AND WITHOUT FLAME RETARDANTS

The individual polymeric materials selected for window fabrication had shown a great potential for such application, however, there was increasing interest regarding their behavior in total window composites when using flame retardant Fyrol FR-2. Each test listed in Table IV was conducted on three films and two laminae constructed of castable polyether urethane (Conathane EN-1554), which in turn had a castable dimethyl RTV silicone laminated on both sides. All tests were performed in accordance with Document MSC-D-NA-0002 (Ref. 3) by National Aeronautics and Space Administration at the NASA-WSTF laboratories. The test materials were identified by MSC (Manned Space Center) serial number as in Table IV.

### Test Results and Discussion

1. Upward Combustion Rate Test

   Test results (Table V) indicated that Sylgard 184 silicone film comparatively had the lowest flame propagation rate of 0.271 in/sec., whereas the addition of 10% flame retardant in Conathane film did not improve the flame retardancy to the level of silicone combustion rate. However, the lamina (4:S/C-F/S) containing flame retardant and encapsulated in dimethyl RTV silicone (Sylgard 184) did show a little improvement and slowed the combustion rate from 0.190 in/sec for lamina S/C/S to 0.160 in/sec. for lamina S/C-F/S containing flame retardant.

   The criteria of acceptability for materials under Category A requirements is:

   a) do not ignite

   b) ignite but self-extinguishing after burning 0.50 inch or less

TABLE IV

WINDOW MATERIALS SELECTED FOR TESTS

| Code No. | Window Materials | Test Performed ** | | | | | | | | MSC Test-Report Number |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Combustion Rate Test (upward) Test #1 | Flash and Fire Point Temp. Test #3 | Odor Test #7 | Carbon Monoxide & Total Organics Test #6 | Thermograph Analysis* | | | | |
| | | | | | | Gen TGA | Exp. TGA | DTG | DTA | |
| 1:C-F | Conathane EN-1554 film with 10% Fyrol FR-2 | x | x | x | x | x | x | x | x | 2965 |
| 2:C | Conathane EN-1554 film | x | x | x | x | x | x | x | x | 2966 |
| 3:S | Silicone - Sylgard 184 film | x | x | x | x | x | x | x | x | 2964 |
| 4:S/C-F/S | Laminate: Sylgard 184/ Conathane EN-1554 with 10% Fyrol FR-2/Sylgard 184 | x | x | x | x | x | x | x | x | 2963 |
| 5:S/C-/S | Laminate: Sylgard 184/ Conathane EN-1554/ Sylgard 184 | x | x | x | x | x | x | x | x | 2962 |

* See Page 152 for explanation and graphs in Appendix C

** See Appendix A for test methods

after extinguishment of the ignitor and do not spark, sputter, or drip flame particles.

Observations indicated that both nonreinforced composites #S/C/S and S/C-F/S burned with intense yellow-orange flames and emitted large amounts of smoke and soot and large numbers of falling burning particles. The residue was a gray-black friable ash. This indicated that the use of flame retardant did not offer any synergistic improvement in preventing the material from burning or falling burning particles.

Summaries of upward flame propagation rate tests are reported in Table V. Complete test data may be found in Data Tables XXIV-A through XXIV-E, Appendix B.

2. Odor Test

All the panels which were tested for odor (see Appendix A for test method) passed at all dilutions. The highest ten member average score was 1.3 at no dilution for Conathane EN-1554 film (1:C-F) containing flame retardant. (An average ten member panel score of 2.5 or lower at any dilution signifies that the material passed the test.) Odor test results for all 5 panels are given in Table V and Data Tables XXVI-A through XXVI-E in Appendix B.

3. Carbon Monoxide, Total Organics, and Flash/Fire Point Test Results

(See Table VI and Data Tables XXVII-A through XXVII-E, Appendix B)

Test results indicated that lamina 5:S/C/S with no flame retardant evolved the lowest amount of carbon monoxide - 0.30 µgm/gm, whereas lamina with flame retardant (4:S/C-F/S) produced the maximum amount of carbon monoxide-0.70 µgm/gm. Similarly, Conathane EN-1554 film (1:C-F) with fire retardant had higher carbon monoxide level of 0.60 µgm/gm than Conathane EN-1554 film (2:C) which was only 0.40 µgm/gm. This suggested that addition

## TABLE V

## SUMMARY OF UPWARD FLAME PROPAGATION RATE* AND ODOR TESTS

| Material Code** | Thickness in. | Upward Flame Propagation Rate in 100% Oxygen @ 6.2 psi | | Odor Test*** Max. Allow. Score <2.5 | | |
|---|---|---|---|---|---|---|
| | | Rate, in/sec. (Avg. of 3 tests) | Observation | A | B | C |
| 1:C-F | 0.045 | 0.386 | Burned with yellow-orange flame, emitted | 0.2 | 0.2 | 1.3 |
| 2:C | 0.020 | 0.382 | Moderate amount of smoke & soot, large amt. of sparks & falling particles | 0.1 | 0.1 | 1.1 |
| 3:S | 0.040 | 0.271 | Burned with intense blue, orange-yellow flames, emitted moderate amt. of smoke, large amt. of fluff & soot, sparks | 0.2 | 0.3 | 0.9 |
| 4:S/C-F/S | 0.090 | 0.160 | Same as in 1:C-F and 2:C | 0.1 | 0.2 | 0.9 |
| 5:S/C/S | 0.090 | 0.190 | Same as in 1:C-F and 2:C | 0.1 | 0.2 | 1.2 |

* See Data Tables XXIV-A through XXIV-E in Appendix B

A 1-part sample atmos. to 29-parts $O_2$

B 1-part sample atmos. to 9-parts $O_2$

C No dilution

** See Table IV

*** Scores reported are average of ten member panel. See Data Tables XXVI-A through XXVI-E

of Fyrol FR-2 flame retardant had contributed toward higher carbon monoxide level. However, in all cases the carbon monoxide level was much lower than maximum allowed level of 25.0 μgm/gm (see Table VI).

Total organic tests revealed that Sylgard 184 film (3:S) had the highest level of 5.1 μgm/gm, whereas Conathane EN-1554 film with flame retardant (1:C-F) had the lowest level of 0.9 μgm/gm among all five panels tested.

4. DTA and TGA Analysis

Thermogravimetry Analysis, Differential Thermal Gravimetry (DTG) and Differential Thermal Analysis (DTA) were also conducted on all five panels.

Differential thermal Analysis (DTA) revealed that Sylgard 184 film (3:S) and Conathane EN-1554 with flame retardant (1:C-F) each had maximum exotherm temperatures in excess of 600° F, whereas laminae (4:S/C-F/S and 5:S/C/S) and Conathane EN-1554 film (2:C) had none. The per cent weight loss observed in Conathane EN-1554 film (1:C-F) with flame retardant was 15.20%, the highest among all five material panels tested, whereas Sylgard 184 silicone showed practically no weight loss up to 600° F test temperature. Results are shown in Table VII and Thermographs (Graphs No. 10 through 14) in Appendix C.

Note: No flame retardant was used in the fabrication of Phase II windows.

TABLE VI

SUMMARY OF CARBON MONOXIDE, TOTAL ORGANICS AND FLASH/FIRE POINT TESTS*

| Material | Carbon Monoxide, μgm/gm Max. Allow. 25.0 | Total Organics, μgm/gm Max. Allow. 100 | Flash Point** | Fire Point** |
|---|---|---|---|---|
| 1:C-F | 0.60 | 0.90 | None up to 600°F | None up to 600°F |
| 2:C | 0.40 | 2.40 | " | " |
| 3:S | 0.50 | 5.10 | " | " |
| 4:S/C-F/S | 0.70 | 2.40 | " | " |
| 5:S/C/S | 0.30 | 1.50 | " | " |

* See Data Tables XXV-A through XXV-E, Appendix B.
** Three samples were tested.

The criteria of a material acceptability for Flash and Fire Points is:

a) A material that evolves vapors which produce a visible flash at a temperature less than 400° F is unacceptable.

b) A material that shows evidence of charring, self-sustaining combustion, or other signs of pyrolysis, such as smoking at a temperature less than 450° F - Unacceptable.

None of the five material panels tested indicated any flash and fire point up to 600° F test temperature. However, material degradation was eminent. For comments on material degradation, see Data Tables XXV-A through XXV-E, Appendix B.

## TABLE VII

## SUMMARY OF THERMOGRAPH ANALYSIS*

| Test Conditions | | | | | DTA** | TGA** | | |
|---|---|---|---|---|---|---|---|---|
| Material | Atmosphere | Pressure Torr. | Heating Rate $^{o}C$/min. | Max. Test Temp., $^{o}C$ | Temp. of Max. Exo-therm, $^{o}C$ | Temp. of Max. Endo-therm, $^{o}C$ | Temp. of Initial Wt. Loss $^{o}C$ | Wt. Loss % |
| 1:C-F | Oxygen | 320 | 10 | 315 | >315 | 245 | 190 | 15.20 |
| 2:C | Oxygen | 320 | 10 | 315 | None | 240 | 230 | 5.10 |
| 3:S | Oxygen | 320 | 10 | 315 | >315 | None | 300 | - |
| 4:S/C-F/S | Oxygen | 320 | 10 | 315 | None | 230 | 230 | 4.60 |
| 5:S/C/S | Oxygen | 320 | 10 | 315 | None | None | 260 | 2.20 |

*For Thermograph Data and Observation, see Data Table XXVIII, Appendix B.

**See Thermographs in Appendix C.

## REINFORCEMENT SELECTION AND EVALUATION

Under NASA Contracts NASI-5524 (Ref. 1) and NASI-7771 (Ref. 2) three types of reinforcing materials were considered for the window - fiberglass, steel, and polyester. The use of polyester filaments was rejected due to: (a) shrinkage of filaments after heat exposure resulting in distortion of the matrix and (b) a very limited viewing area was available if the required matrix design strength had to be met.

Fiberglass rovings and steel wire were further evaluated in the window composite under Contract NASI-7771 (Ref. 2). Fabrication of window composite using glass rovings posed serious problems of uneven tension on filaments during winding, breakage of filaments due to poor abrasion resistance, non-uniform diameter of roving, "flatten-out" effect in the matrix pattern, and inadequate adhesion for window application.

The task of an exact match of the index of refraction of fiberglass and the matrix materials over the range of expected temperatures and light wavelengths appeared to be extremely difficult, if not impossible, to attain.

With this background,brass plated steel wire cable was selected. High strength steel wire offered the advantages of easier handling and less likelihood of strand damage during fabrication, better flexibility in cable, in the reduction of the number of individual strands required, more uniform tension and higher load transfer efficiency factor, and a more uniform pattern contributing to superior optical transparency.

During Phase I and Phase II of this contract, two types of steel wire were used as reinforcements. The details are given in Table VIII.

TABLE VIII

REINFORCEMENT MATERIAL PARAMETERS

| Code | Reinforcement Material | Overall Diameter mm | No. of Strands | Ultimate* Breaking Strength (min)nts. | Supplier |
|---|---|---|---|---|---|
| R-1 | Brass plated high strength wire cable (3 x 3 x .004) | 0.3429 (.0135") | 9 | 131.23 | National Standard Corp. |
| R-2 | Brass plated carbon rocket wire cord | .2540** (.010") | 7 | 132.12** | National Standard Corp. |

*Lowest strength data obtained among 12 test samples.
See Appendix B for test data and Appendix A for test method.

**After black coating on the wires.

During the entire evaluation and testing process under both phases of this contract, only R-1 steel wire cable was used for fabrication technique evaluation. Due to a limited supply of R-2 carbon rocket wire cord, only two models (one subscale window model of 15.2 cm diameter by 20.3 cm long and the other, a 45.7 cm diameter by 61.0 cm long cylindrical window) were fabricated out of black coated* R-2 wire, and these windows were shipped to NASA for further evaluations.

*See page 82 for details on black coating on reinforcement R-2 materials.

## PHASE I

## REINFORCEMENT EMBEDMENT METHOD EVALUATION

In order to determine the most promising window fabrication technique, various methods of embedding the reinforcement members in the wall of a collapsible cylindrical window were given consideration. A netting pattern with reinforcements lying parallel to and very nearly perpendicular to the main axis of the cylinder was utilized throughout except for those used for reinforcement angle evaluation. Construction of the netting patterns in Phase I and Phase II windows were as given in Table XI. Every effort was made to maintain the total wall thickness of windows at a maximum of 0.279 cm (0.110 inch).

Each method of embedment was evaluated for:

a. Adequacy of reinforcement coverage and controllability of polymer buildup.

b. Surface finish, that is, freedom from runs, pockmarks, "orange peeling", etc.

c. Clarity of polymer film

d. Ease of fabrication

e. Reproducibility

In the evaluation of the following embedment methods, Conathane EN-1554 (polyether polyurethane) was used as a basic window matrix polymer and Sylgard 184 (dimethyl RTV silicone) as the surface "barrier" material. Brass plated high strength wire cable of 9 strands (R-1, Table VIII) having an overall diameter of 0.3429 mm was utilized as the reinforcement material.

Reinforcement embedment methods evaluated were:

1. A. Spraying

   Cast film applied to mandrel

B. Spin or dip casting

C. Vacuum encapsulation

2. Other concepts of cylindrical window fabrication considered were:

A. Partial embedment - girth reinforcement to be embedded in matrix, axial reinforcements applied to external surface of cylinder in the form of a cage.

B. Polymeric matrix with equi-spaced girth reinforcement in the form of bead rings; no axial reinforcement.

C. No reinforcement members - urethane/silicone matrix built to varying thickness.

None of the above "other" concepts for cylindrical window fabrication showed as much potential as the technique involving the combination of "vacuum encapsulation and cast film applied to mandrel", therefore, no attempts were made to evaluate "other" concepts. Bearing upon this decision were the facts that the cylindrical window must meet various requirements such as minimal dimensional change under pressure and achieve ultimate strength goal of 829 n/cm, etc. It seemed very unlikely, if not impossible, to achieve the objectives set forth using any of the "other" concepts mentioned.

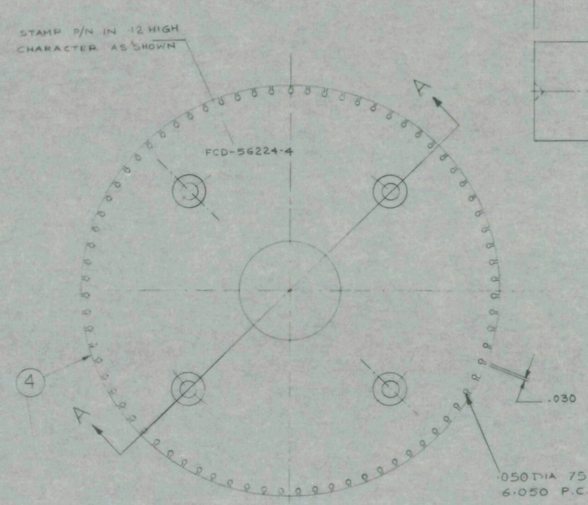
## DESCRIPTION OF REINFORCEMENT METHODS EVALUATED AND PROBLEMS INVOLVED

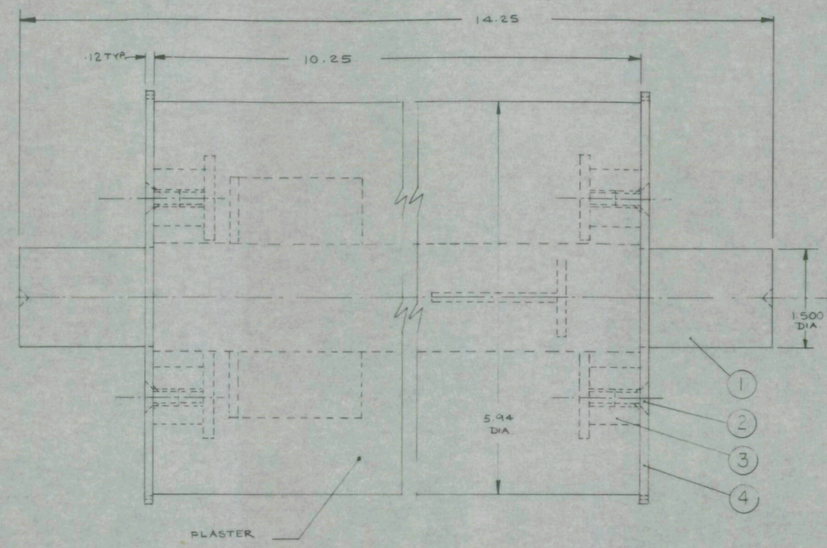
### A. Cast Film Applied to Mandrel and Spraying Techniques

For this evaluation, a subscale plaster mandrel (15.0 cm diameter by 26.0 cm length) fitted with end discs, having grooves for winding the reinforcement, was designed as shown in Figure 1. The mandrel surface was coated with water soluble PVA for releasing the window.

A cast film of urethane was applied to the PVA coated mandrel and a netting pattern, with reinforcements parallel to the mandrel axis, was laid upon

| REVISIONS | | | |
|---|---|---|---|
| SYM. | DESCRIPTION | DATE | APPROVAL |
| | | | |




PLASTER MANDREL ASSEMBLY

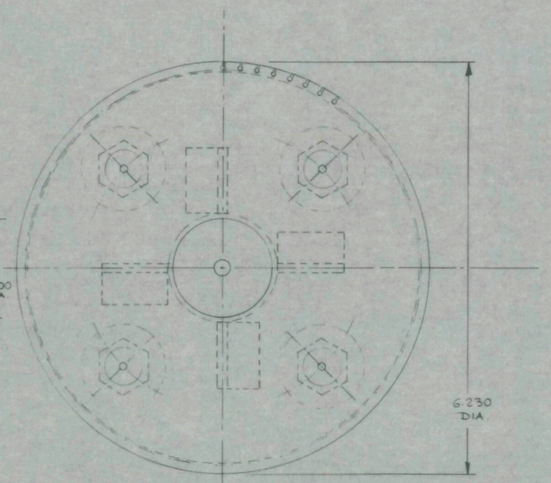
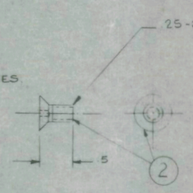
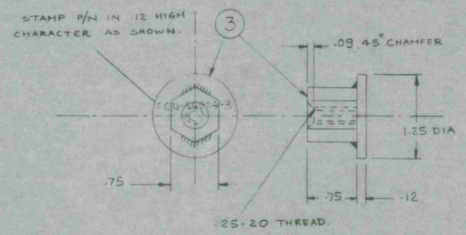
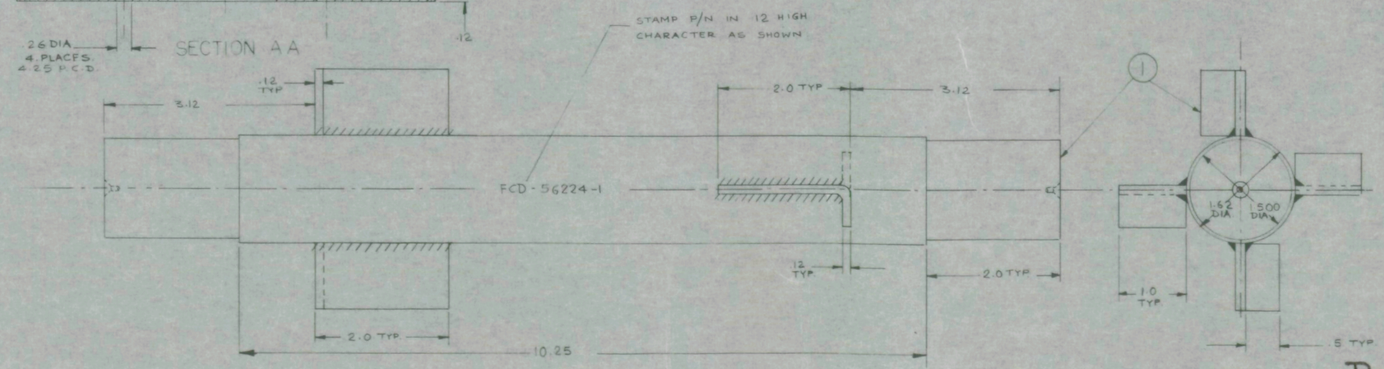



FIGURE 1 PLASTER MANDREL FOR THE EVALUATION OF PHASE I FLEXIBLE WINDOW FABRICATION METHOD USING DIP OR CASTING TECHNIQUE.




| QTY. REQ'D | SYM. | NOMENCLATURE OR DESCRIPTION | CODE IDENT. | PART OR IDENTIFYING NO. | SPECIFICATION | MATERIAL | UNIT WT. | ZONE | ITEM NO. |
|---|---|---|---|---|---|---|---|---|---|
| 2 | | WIRE WINDING PLATE | | FCD-56224-4 | | ALUM. | | | 4 |
| 8 | | THREADED INSERTS | | FCD-56224-3 | | STEEL | | | 3 |
| 8 | | FLAT HEAD SOCKET CAP SCREW .25 SIZE | | FCD-56224-2 | | STEEL | | | 2 |
| 1 | | SHAFT | | FCD-56224-1 | | ALUM. | | | 1 |

LIST OF MATERIALS

| | |
|---|---|
| DRAWN BY | D DIGHE 6/24/70 |
| DES. | D DIGHE 6/24/70 |
| CHECKED BY | D. DIGHE 6/27/70 |
| APPD. BY | D. DIGHE 6/27/70 |

UNIROYAL, Inc.
ENGINEERED SYSTEMS DEPARTMENT
MISHAWAKA, INDIANA 46544

PLASTER MANDREL FOR CYLINDRICAL WINDOW

| CODE IDENT. NO. | SIZE | |
|---|---|---|
| 00333 | D | FCD-56224 |
| SCALE FULL | LANGLEY - NASA | SHEET 1 OF 1 |

FCD-56224

the cast film. Urethane polymer, with the necessary additives, was sprayed on the netted surface of the mandrel using hand air-spray-gun. (The mandrel was kept rotating to prevent polymer dripping.) There were two main problems encountered during this evaluation:

1. The urethane polymer mixture had to be diluted excessively in order to allow free flow of material through the spray-gun. This presented difficulties in the build up of the required wall thickness and produced a very uneven surface.
2. During spraying, air was trapped, developing myriad minute cells. Consequently, the visibility of the window was completely obscured.

In order to overcome the above two problems, another trial was run using another plaster mandrel.

In this second trial, liquid urethane of suitable viscosity (no excessive solvent used for dilution) was poured on to the netted surface of the mandrel, instead of spraying, while the mandrel was rotated at a suitable speed on a lathe. The problem of air entrapment was partially solved, but still there were minute air cells present which could not be eliminated. Uneven surface, runs, pockmarks, and the most important, poor visibility, were also the major factors contributing toward the rejection of this method. An electrostatic spraying technique was also considered unsatisfactory due to air entrapment problem.

B. Spin or Dip Casting

In this evaluation, the same PVA coated plaster mandrel was used. A very thin coat of silicone (Sylgard 184) was first applied to the surface of the PVA coated plaster mandrel to obtain smooth surface. The

axial reinforcement was next wound and the mandrel was partially immersed horizontally into urethane polymer (Conathane EN-1554) while rotating. After a partial cure of the applied urethane polymer, girth winding was completed and again the mandrel partially immersed into liquid Conathane EN-1554 to cover the reinforcements and to develop the necessary thickness build up.

The window made by this technique had improved visibility; but poor controllability, of polymer build up and the presence of pockmarks, orange peel effect, and minute air bubbles, made this technique unacceptable.

Another trial was conducted using a preapplied film onto the plaster mandrel and axial and girth reinforcements wound on it. Spin and dip casting technique was followed. During this evaluation I.R. (infrared) bulbs were used to heat and partially cure the window while rotating on lathe. It was anticipated that heat would remove the air bubble from the outer layer of liquid urethane on the mandrel surface, but this did not completely eliminate the air entrapment.

C. Vacuum Encapsulation

This was the most promising technique for fabrication of reinforced cylindrical windows. However, the use of vacuum encapsulation alone involved two unfavorable parameters:

1. Without first applying urethane film on the surface of the male-section mold, there was no support for the axial reinforcement when the girth reinforcement was wound under tension on the axial reinforcement. This resulted in the deviation of the netting pattern reinforcement and reinforcement/mold contact; thus, the embedment of the reinforcement in the center of the total wall thickness was impossible.

VAC CHAMBER - NASA
FLEXIBLE SPACE WINDOW
LOCKHEED GEORGIA COMPANY
REVISION
DATE BY APP.

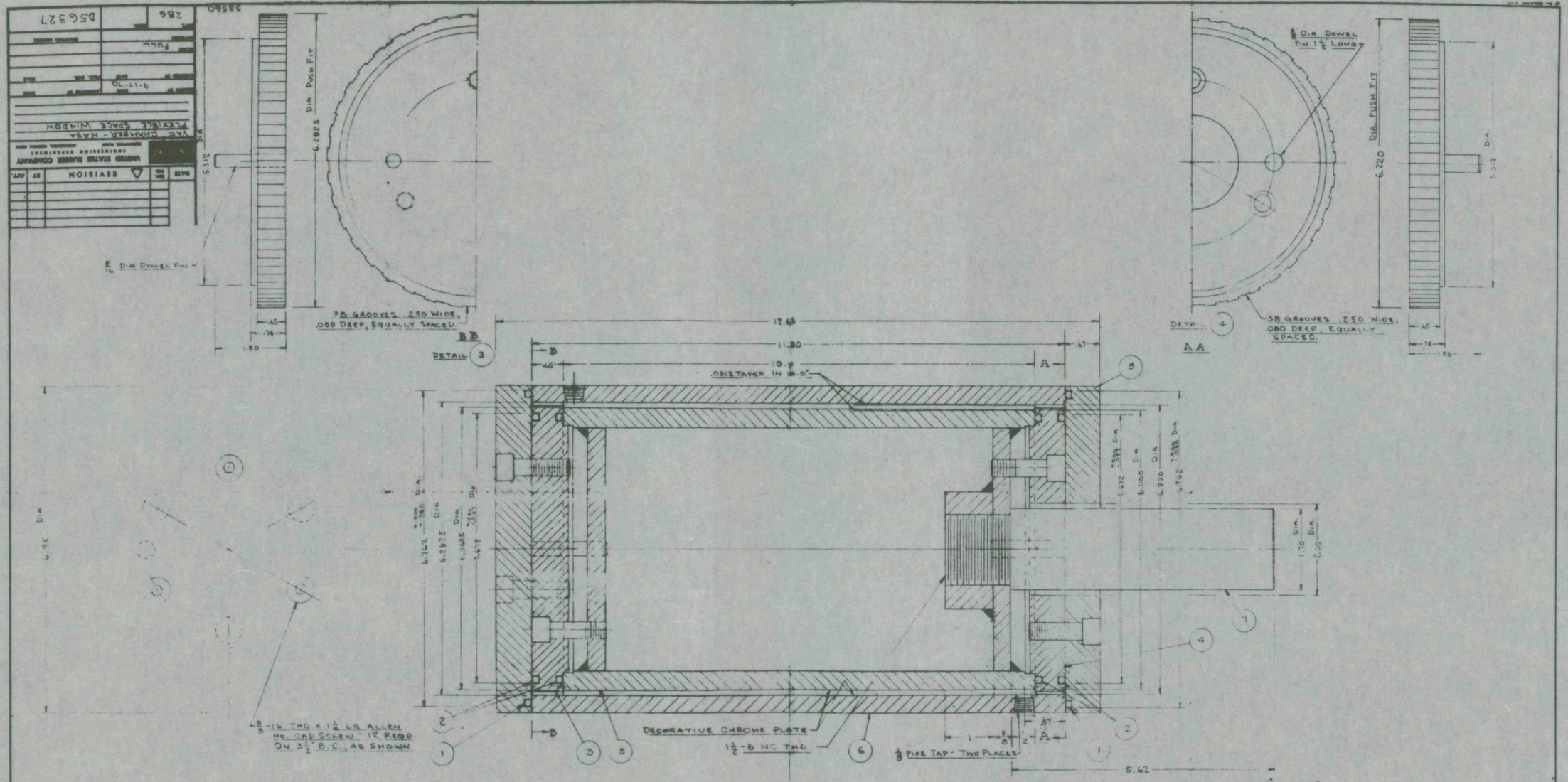



FIGURE 2. VAC-MOLD FOR PHASE I FLEXIBLE WINDOW FABRICATION

| QUAN. | DESCRIPTION | PART NO. | MAT'L. | ITEM NO. |
|---|---|---|---|---|
| 1 | CAP PLATE, BLIND END | | STEEL | 9 |
| 1 | CAP PLATE, STUD END | | STEEL | 8 |
| 1 | SHANK | | STEEL | 7 |
| 1 | TAPERED SHELL | | STEEL | 6 |
| 1 | TAPERED MANDREL | | STEEL | 5 |
| 1 | GROOVED PLATE | | STEEL | 4 |
| 1 | GROOVED PLATE | | STEEL | 3 |
| 4 | "O" RING .139 DIA | PARKER NO. 254 | NEOPRENE | 2 |
| 2 | "O" RING .139 DIA. | PARKER NO. 260 | NEOPRENE | 1 |

LIST OF MATERIAL

2. Consideration was given to the vacuum casting of the inner urethane film on the male-mold section, application of the reinforcement netting, and the vacuum casting of a urethane film over the reinforcement. This concept was later discarded for the following reasons: (a) Two female section molds were required. One for use in the casting of the first film on the male mold and a second for use in casting the urethane film over the reinforcement netting. The two female-mold sections varied in inside diameters by the difference between the outside diameter of the first film applied and the outside diameter developed by the reinforcement and the outside, or cover film applied. (b) Experience has shown that the urethane films will shrink slightly during cure. The combination of a very smooth inner surface and the shrinkage inherent in the urethane film would produce a condition such that it would be impossible to remove the window, from the male-section of the mold, without severe and excessive distortion.

Due to the preceding reasons, another technique was conceived which involved the combination of "cast film applied to the mandrel" for an inner layer and "vacuum encapsulating" for the outer layer. This combined technique was the most successful in fabricating cylindrical windows in Phase I and Phase II. In order to fabricate the subscale windows, a metal vac-mold was designed as shown in Figure 2. The combination technique used is described separately for Phase I and Phase II window fabrication.

Table IX shows the comparative results of each embedment method considered in this program.

TABLE IX

SUMMARY OF REINFORCEMENT EMBEDMENT METHODS EVALUATION

| Method | Adequacy of Reinforcement Coverage | Controllability of Polymer Buildup | Surface Finish Free Of | | | | Clarity of Polymer Film | Ease of Fabrication | Reproducibility | Resultant Window Acceptance Criteria |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Runs | Pockmarks | Air Entrapment | Orange Peel Effect | | | | |
| Spraying | P | P | P | P | V.P. | P | V.P. | F | P | P |
| Cast Film Applied to Mandrel and Spraying | P | P | P | P | P | F | P | F | F | P |
| Spin or Dip Casting | F | P | F | P | F | P | F | F | P | F |
| Vacuum Encapsulation | G | V.G. | G | G | G | G | V.G. | P | G | G |
| Combination of Preapplied Film and Vacuum Encapsulation | V.G. | V.G. | G | G | V.G. | V.G. | V.G | V.G. | V.G. | V.G. |
| Others: | | | | | | | | | | |
| Partial Embedment | P | V.P. | P | P | F | P | F | V.P. | P | V.P. |
| No Axial Reinforcement but Bead Rings in Girth | P | V.P. | P | P | F | P | F | V.P. | P | V.P. |
| No Reinforcement | - | F | F | F | F | F | F | F | F | V.P. |

Rating

V.G.: Very Good G: Good P: Poor
F: Fair V.P: Very Poor

## REINFORCEMENT ANGLE EVALUATION

### A. Effect of Reinforcement Angles on Window Composite Strength and Window Fitting Attachment

Before the selection of reinforcement angles for evaluation in Phase I cylindrical windows, a mathematical analysis was carried out to determine the effect of a reinforcement angle on the stress developed in the window wall composite due to internal pressure and also the load exerted on the axial reinforcement wire loops in the cylindrical windows.

As the ultimate strength goal for the flexible window was at least 829 n/cm (470 lbs/in) in the direction of maximum stress (girth direction), it was necessary to first determine the optimum reinforcement angle under which the ultimate strength of the window composite could be attained when the cylindrical window was pressurized to 40.8 nscm (58.8 psig). Windows of 15.52 cm diameter (Phase I) and 46.00 cm (Phase II) were considered for mathematical analysis as follows:

Mathematical Analysis

Consider a cylindrical window having reinforcement members at angles $\theta$ and $\phi$, as shown in Figure 3A.

Assuming,

$\theta$ = Angle (degrees) made by the axial wires with the axis of cylinder
P = internal pressure, psi
D = mean diameter, in.
$T_1$ = tension in pounds per inch
$T_2$ = tension in pounds per inch

$\Gamma$ = shear stress in lb/in, thickness of film
$\phi = 90-\theta$

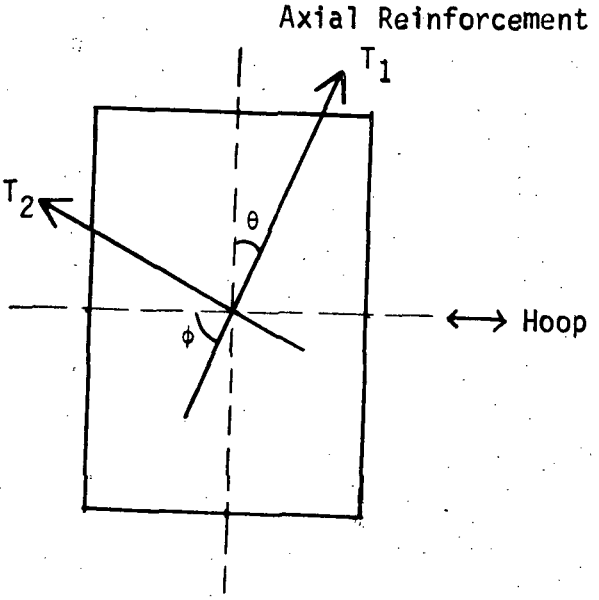



FIGURE 3A

Then, the following expressions (Ref. 5) can be set up involving the above related parameters:

$$T_1 = \frac{3PD}{8} + \frac{PD}{8} \text{ Cos } 2\theta \qquad (1)$$

$$T_2 = \frac{3PD}{8} - \frac{PD}{8} \text{ Cos } 2\theta \qquad (2)$$

$$\Gamma = \frac{PD}{8} \text{ Sine } 2\theta \qquad (3)$$

In the fabrication of the cylindrical windows, the girth winding was done at a pitch of 0.635 cm (¼ inch). This produced an angle of approximately 0.75 degrees ($0^o45'$) in the girth direction for windows under Phase I. (Figures 3B and 3C).

For windows of 15.52 cm (6.11 in.) diameter,

$$\text{Tan } \alpha = 0.0130$$
$$\text{or}$$
$$\alpha = 0.747^o$$

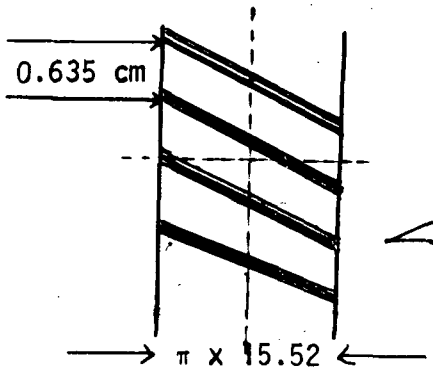


FIGURE 3B

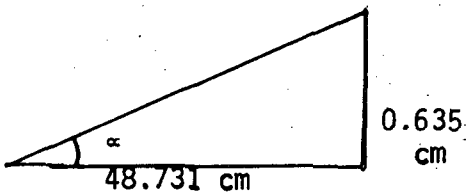


FIGURE 3C

For windows of 46.0 cm diameter (18.110 in.) under Phase II, the girth reinforcement angle produced by 0.635 cm (¼ in.) "lead" during girth winding is 0.252 degrees (approximately $0^o15'$).

As the girth winding angle in both cases is very small as compared to the axial reinforcement angle, it could be considered negligible. Therefore, using equations 1 and 2, window composite strength, at various reinforcement angles were estimated as follows:

For Phase I Windows,

| | | |
|---|---|---|
| Window diameter | = | 15.52 cm (6.110 in) |
| Internal pressure | = | 40.8 nscm (58.8 psig) |
| $\theta$ | = | $0^o$ |
| $\phi$ | = | $90^o$ |

Therefore, from equations 1 and 2:

$T_1 = 44.908 (3 + \text{Cos } 180)$ = 89.82 lb/in (158.50 n/cm)

$T_2 = 44.908 (3 - \text{Cos } 180)$ = 179.64 lb/in (317.00 n/cm)

Similarly, Table X was constructed to estimate the effect of axial reinforcement angles on a window composite under pressure.

Table X indicated that the axial reinforcement angle in 46.0 cm diameter cylindrical windows should be less than or equal to 29 degrees in order to achieve the strength goal of 829 n/cm (470.0 lbs/in) in the direction of maximum stress.

Figure 4 shows the effect of axial reinforcement angles on the tension developed in the window wall composite due to internal pressure.

B. Reinforcement Angles Selected for EValuation (Phase I)

One of the primary requisites for cylindrical observation windows was that they be collapsible to at least one-sixth of their original length, hence, it was of utmost importance that the reinforcement angle selected for the window construction be correct. Bulge or elongation beyond the intended dimensions were undesirable factors for collapsible observation windows. As a result of the observation window requirements, three different reinforcement angles were selected for Phase I window evaluations: 0 degree, 7 degrees and 15 degrees. Evaluation of a higher reinforcement angle of $25^{o}$ was abandoned due to the vac-mold winding plate's grooves (see Figure 2) producing an uneven pattern and reinforcement bending during axial winding.

C. Criteria for Reinforcement Angles Evaluation

In order to select a reinforcement angle, which would allow for a twisting pantographing motion, subscale cylindrical windows (15.2 cm diameter by 20.3 cm long) were fabricated, and then evaluated for the following

TABLE X

RELATIONSHIP BETWEEN AXIAL REINFORCEMENT ANGLES AND TENSION IN FLEXIBLE WINDOW WALL COMPOSITE

| | Phase I | | Phase II | |
|---|---|---|---|---|
| Window Diameter<br>Internal Pressure | 15.52 cm<br>40.8 nscm | | 46.0 cm<br>40.8 nscm | |
| Axial Reinforcement Angle θ (degree) | Axial Tension n/cm | Hoop Tension n/cm | Axial Tension n/cm | Hoop Tension n/cm |
| 0 | 158.5 | 317.0 | 469.7 | 939.5 |
| 7 | 160.8 | 314.6 | 476.8 | 932.6 |
| 15 | 169.1 | 306.4 | 501.1 | 908.7 |
| 19 | 175.3 | 300.2 | 519.5 | 889.7 |
| 25 | 186.8 | 288.7 | 553.7 | 855.6 |
| 29 | 195.7 | 279.7 | 580.2 | 829.2 |
| 45 | 237.7 | 237.7 | 704.6 | 704.6 |
| 60 | 173.3 | 95.8 | 822.1 | 587.2 |

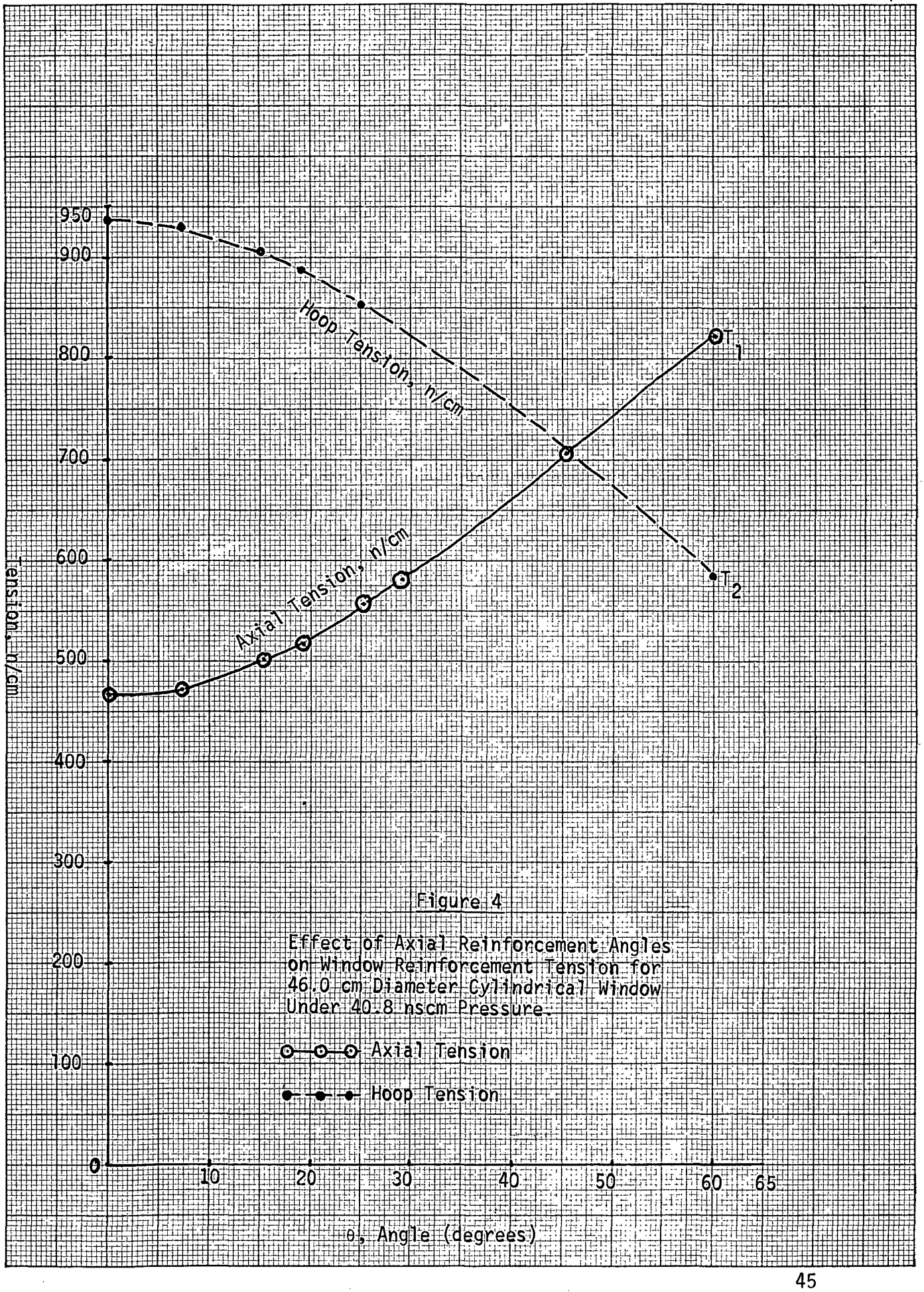



Figure 4

Effect of Axial Reinforcement Angles on Window Reinforcement Tension for 46.0 cm Diameter Cylindrical Window Under 40.8 nscm Pressure.

parameters:

a. collapse of cylinder

b. change in dimensions after extension/collapse cycles

c. dimensional changes under pressure of 3.471 nscm, 6.943 nscm, and 10.413 nscm

d. material degradation due to repeated cycling through extension/collapse.

Details of the netting pattern used for reinforcement angle evaluation are as in Table XI while window fabrication and testing details are described later.

PHASE I

TABLE XI

CYLINDRICAL WINDOWS SELECTED FOR REINFORCEMENT ANGLE EVALUATION

| Code | Subscale Windows | Winding Angle (degree) w.r.t. Cylinder axis** | | Reinforcement Used per 2.54 cm (R-1 type)* | |
|---|---|---|---|---|---|
| | | Axial | Girth | Axial | Girth |
| US-10<br>US-11<br>US-12 | 15.24 cm diameter by 20.32 cm length | 0<br>0<br>0 | 0.75 | Group of 2 ends, total of 8 ends | Group of 4 ends, total of 16 ends |
| US-17 | " | 7 | 0.75 | " | " |
| US-20 | " | 15 | 0.75 | " | " |

*Brass plated wire used (See Table VIII for details)

**Pitch of 0.635 cm (¼ in) was used during girth winding

## FABRICATION OF REINFORCED CYLINDRICAL WINDOWS FOR PHASE I

### A. Evaluation of Release Agents

In order to produce optically transparent reinforced cylindrical window, a steel vac-mold was designed. The vac-mold chamber consisted of two winding plates having equi-spaced grooves for winding axial wire reinforcements at a minimum distance of 0.63 cm, a chrome plated male-section mold having a microfinish of 2 on the surface and a female-section mold having an inside chrome plate microfinish of 2. The mold had a slight taper to facilitate removal of the fabricated window. The detail drawings for Phase I vac-mold is shown in Figure 2.

Seven vac-mold trials were conducted to overcome the following two major problems:

a. Release of window film from the surface of male-section mold.

b. Prevention of air entrapment in the outer layer of the window while vacuum casting.

Several release agents were considered for the release of window film from the male and female sections of the vac-mold. Release agent evaluations included:

1) MS-122* (fluorocarbon - dry lubricant) on both sections of the mold.

2) Lux soap solution on both sections of the mold.

3) Johnson Wax* (paste) on both sections of the mold.

4) MS-122* on female-section and Johnson Wax on the male-section mold.

5) RAM-225* on female-section and Johnson wax on the male-section mold.

*See List of Material Suppliers

6) DC-55* (silicone grease) on male-section and RAM-225 on the female-section mold.

7) DC-55* on the male-section mold and then two layers of 0.0254 mm thick Mylar film on it and RAM-225 on the female-section mold.

*See List of Material Suppliers

Only the combination of DC-55 and Mylar film on the male-section and RAM-225 on the female-section mold was found satisfactory for window fabrication. Later on only one layer of Mylar film (0.0254 mm thick) was used throughout the window fabrication program under Phase I and Phase II. Other release agents or combinations of agents either did not release or produced cloudy films.

B. Procedure for Subscale Window Fabrication - Phase I
(Combination of preapplied film and vacuum encapsulation technique)

1. Mold Preparation

One coat of DC-55 release agent was applied to the surface of the male-section mold and then one layer of Mylar film (0.0254 mm) was wrapped around the mold to cover the entire cylindrical surface. A precast Conathane EN-1554 film of approximately 1.00 mm to 1.15 mm thickness, cut to the size of the male-section mold, was applied to the Mylar film surface. The two longitudinal edges of the Conathane EN-1554 films were firmly joined using Conap AD-1146 adhesive. Axial reinforcements were hand wound while girth winding was performed on a modified lathe. MS-122 (fluorocarbon release agent) was sprayed on only window loop wires to release them from urethane polymers.

RAM-225 was applied on the inside of the female-section mold and baked at 275$^{0}$ F for one hour before assembling the mold for vac trial.

2. Vac Trials

A total of twenty vac-trials were conducted to fabricate the cylindrical windows (15.2 cm diameter by 20.3 cm length) under the Phase I program. The first trials were to perfect the fabrication technique. Initial vac trial windows had voids, pockmarks and a one to one and one-half inch unfilled portion at the top. Such imperfections were overcome by feeding the air free urethane polymer in at the bottom of the mold, raising the urethane-trap-pot head higher than the mold outlet, and continuing vacuum until a bubble free stream of urethane started coming through the mold outlet.

After the vac trial, the whole mold assembly was heated up for 15-16 hours at 160-170$^{o}$ F to cure the film.

3. Application of Silicone (Sylgard 184) Film Barrier on Urethane Surfaces of Cylindrical Window

For silicone application on the inside and outside window surfaces, window fittings were attached to the window reinforcement loops and then the window was mounted on a lathe.

One coat of Chemlok 607 adhesive (clear solution of 50/50 Chemlok 607 and methanol) was applied to the inside and outside surfaces of the window while the window was rotating on the lathe.

Liquid RTV Sylgard 184 with the necessary curative added was poured on the inside and outside surface of the window and kept on rotating for 15-16 hours at room temperature until it partially cured for further handling. Post curing of Sylgard 184 was done at 190$^{o}$ ± 10$^{o}$ F for 1 hour.

C. Conclusion

Fabrication of reinforced cylindrical windows, using the tenchique

developed by combining preapplied film and vacuum encapsulation methods, was found to be the best among all other reinforcement embedment methods evaluated. This technique was employed throughout to fabricate windows for evaluation.

A comparative analysis of each method of embedment is summarized in Table IX. Cylindrical windows with three reinforcment angles were tested to select one angle for the fabrication of Phase II windows.

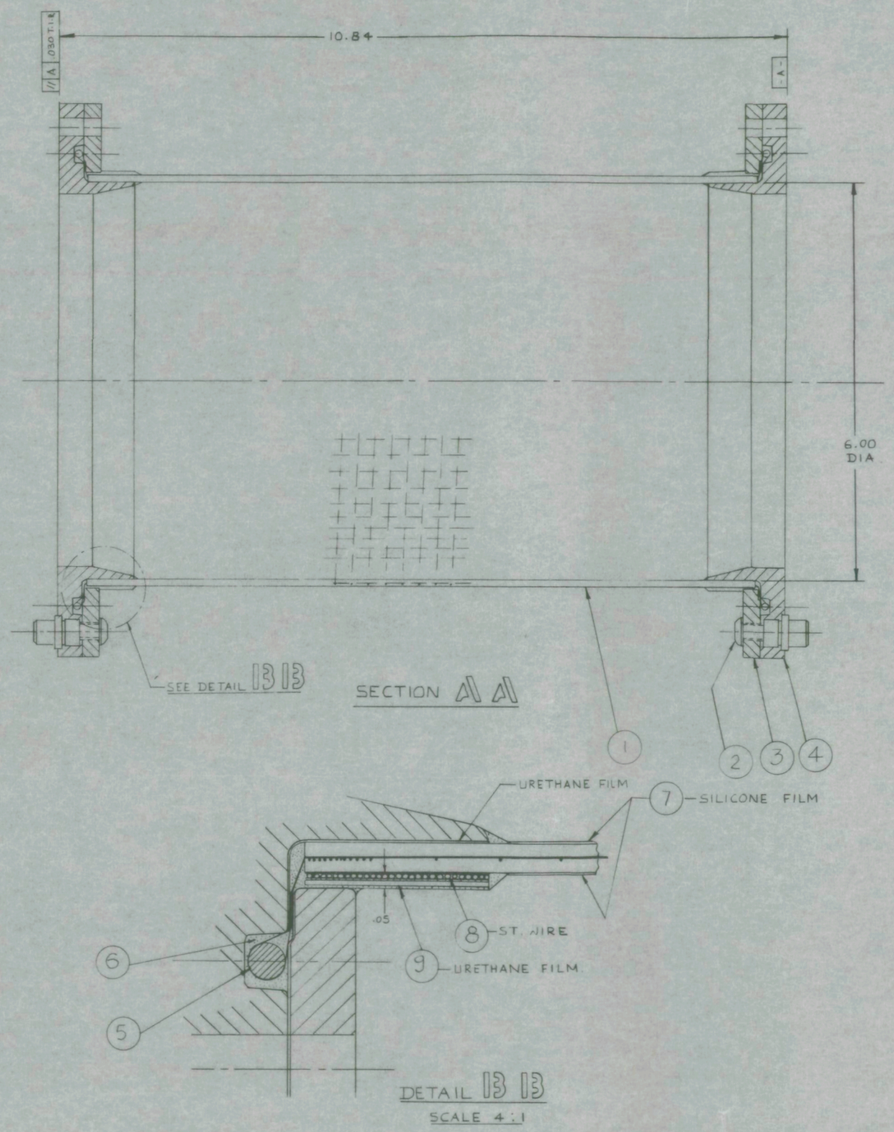
## FITTING ATTACHMENT SYSTEM FOR PHASE I WINDOWS

A system was developed to attach the flexible window to rigid metal fittings. Due to the inherent bonding characteristics of urethane polymer, the window wall composite initially was bonded to the metal fitting wall using urethane adhesive as shown in Figure 5 (Detail BB).

In order to prevent delamination and retain an airtight seal under pressure, steel wires were tightly wound circumferentially about the ends of the window assemblies in such a manner as to tightly clamp the transparent cylinder to the vertical fitting flange. Axial reinforcement hoops were held under the circular clamping ring by means of an "O" ring passing through each loop.

A test conducted on a 15.2 cm diameter cylindrical window showed no sign of fitting attachment failure for pressures up to 41.65 nscm (60.0 psig).

A detailed description of Phase I window fittings and attachment system is shown in Figure 5.



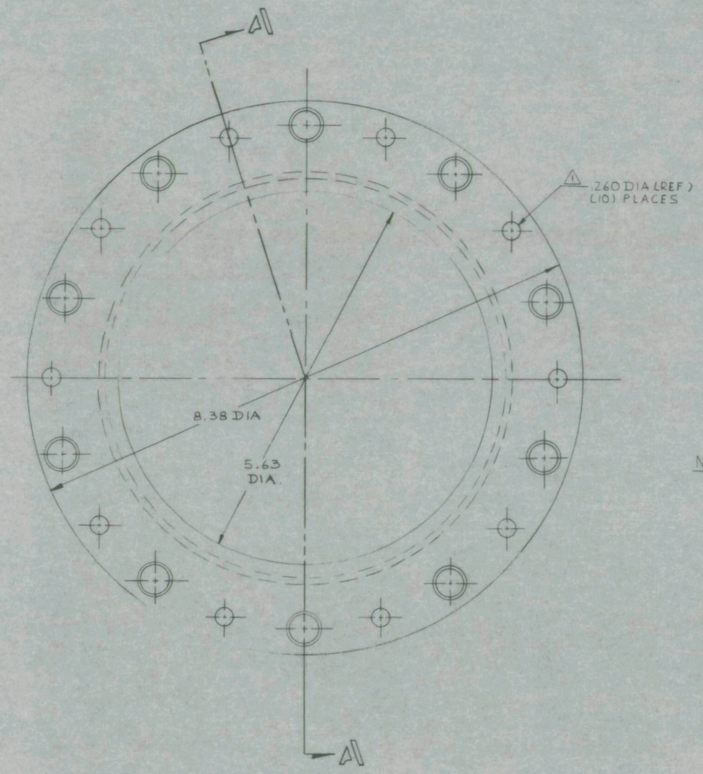




FIGURE 5. PHASE I FLEXIBLE WINDOW FITTING AND ATTACHMENT SYSTEM.

| REVISIONS | | | |
|---|---|---|---|
| SYM. | DESCRIPTION | DATE | APPROVAL |
| | | | |

NOTES:

1. ALLIGN HOLES IN RINGS AT BOTH ENDS WITHIN .010 T.I.R.
2. MAX. TORQUE ON CAP SCREW DURING ASS'Y TO BE 80 IN. LB.

| QTY. REQ'D | SYM. | NOMENCLATURE OR DESCRIPTION | CODE IDENT. | PART OR IDENTIFYING NO. | SPECIFICATION | MATERIAL | UNIT WT. | ZONE | ITEM NO. |
|---|---|---|---|---|---|---|---|---|---|
| A/R | | URETHANE FILM | | | CONAP-URETHANE | | | | 9 |
| A/R | | ST. WIRE | | | 3 x 34 .004 - .017 DIA BRASS PLATED. | | | | 8 |
| A/R | | SILICONE FILM | | | DOW-CORNING SYLGARD-184-SILICONE | | | | 7 |
| A/R | | ADHESIVE | | | UNIROYAL URETHANE ADHESIVE 41763-1 | | | | 6 |
| 2 | | BEAD RING | | FCD-56323 | | STL. | | | 5 |
| 2 | | RING | | FCD-56225 | | ALUM. | | | 4 |
| 2 | | CLAMPING RING | | FCD-56322 | | ALUM. | | | 3 |
| 20 | | BUTTON HEAD SOCKET CAP SCREW. | | | 1/4-28 x 1/2 | STD. | | | 2 |
| 1 | | WIRE REINFORCED FLEX. WINDOW CONSTRUCTION. | | FCD-56324 | CONAP-URETHANE & STEEL WIRE | | | | 1 |

LIST OF MATERIALS

TOLERANCE: UNLESS NOTED -
ON .X ± .10
ON .XX ± .030
ON .XXX ± .005
ON ANGLES ± 0° 30'

| | | |
|---|---|---|
| DRAWN BY | D. DIGHE | 7-31-70 |
| ENGR. | D. DIGHE | 7-31-70 |
| CHECKED BY | | |
| APPR. BY | | |

UNIROYAL, Inc.
ENGINEERED SYSTEMS DEPARTMENT
MISHAWAKA, INDIANA 46544

FLEXIBLE OBSERVATION WINDOW ASSEMBLY.

CODE IDENT. NO. 00333 | SIZE D | FCD-56325

SCALE FULL | NASA-LANGLEY | SHEET 1 OF 1

FCD-56325

# PHASE I

# WINDOW TESTING

## PHASE I - WINDOW TESTIIIG PROCEDURE

For the determination of dimensional changes, scale and calipers were used to measure the length and outside diameter of the cylinder before and during pressure testing. Cylindrical windows were held for a least 15 minutes under pressure levels of 3.471 nscm and 6.943 ncms and 24 hours under 10.413 nscm pressure before making any dimensional measurements. For dimensional measurements during collapse/extension cycles, at least 5 minutes were allowed for relaxation after each extension cycle, and 5 minutes in a collapsed condition. In each collapse cycle, the window was twisted and brought to the same collapsed position.

Material degradation, due to repeated collapse/extension cycles, was determined by visual examination, whereas optical transparency and clarity of the window composites were determined using the Human Factors Eye Chart and the Optical Standards established in NASA Contract NASI-7771 (Ref. 2).

For the collapsibility test, one of the fittings attached to axial reinforcement wire loops (see fitting attachment system) was installed in a rigid frame while at the top, a torque wrench (with in.-lb. graduation) was used to twist the window down manually. The torque-range position was also noted (see Torque Data in Data Table XXX, Appendix B).

## PHASE I- WINDOW TESTING RESULTS

A. Dimensional Changes

1. Window Dimensional Changes Under Pressure

Four subscale windows were evaluated in order to determine the effect of reinforcement angle on the dimensional changes produced through window pressurization. Windows #US-10 and US-19 had the axial reinforcement member parallel to the cylindrical window axis, whereas window #US-17 and US-20 had axial reinforcement at an angle of 7 degrees

15 degrees respectively. Each window's length and diameter changes were determined at three pressure levels - 3.471, 6.943 and 10.413 nscm. Results indicated that the overall dimensional changes in windows with no angle in the reinforcement member were smaller than the window with reinforcements at an angle of 15 degrees. However, the changes were so small that the effect of the reinforcement angle on dimensional changes within the pressure range of 3.671 nscm to 10.413 nscm was hardly noticeable. Test results are shown in Table XII and Test Data Table XXIX.

2. Dimensional Changes Due to Collapse/Extension Cycles

Attempts were also made to determine the effect of reinforcement angle on the dimensional changes produced in the subscale windows after 10 cycles of collapse/extension and also after 24 hours in collapsed condition.

Results indicated that windows #US-10, US-17 and US-20 containing axial reinforcement at angles - 0 degress, 7 degrees, and 15 degrees respectively attained essentially their original length very shortly after 10 cycles of collapse/extension. There were a few highly stressed areas, however, which needed a longer time to creep back to their original position.

All the windows tested had a few depressed areas when released after 24 hours in the collapsed condition, but the depressions diminished rapidly with time. Pressurization of the windows eliminated the depressions entirely. Figures 6 through 8 show the ability of a subscale window (with reinforcement angle at $0^{o}$) to retain the structural integrity and dimensional stability after collapse/extension cycles.

In general, the torque necessary to collapse the window was lower for windows with the reinforcement at $0^{o}$ angle compared to windows with

PHASE I

TABLE XII*

SUMMARY OF DIMENSIONAL** CHANGES UNDER PRESSURE

| Window Code | Angle of Axial Wire (degrees) | Avg. Percent Changes Under Pressure | | | | | |
|---|---|---|---|---|---|---|---|
| | | 3.471 nscm | | 6.943 nscm | | 10.413 nscm | |
| | | Length | Diameter | Length | Diameter | Length | Diameter |
| US-10 | 0 | 0.136 | 0 | 0.136 | 0 | 0.204 | 0.212 |
| US-19 | 0 | 0.274 | 0.321 | 0.411 | 0.851 | 0.411 | 0.850 |
| US-17 | 7 | 0.067 | 0 | 0.338 | 0.106 | 0.338 | 0.106 |
| US-20 | 15 | 0.274 | 0.532 | 0.411 | 0.957 | 0.411 | 0.957 |

*For data see Data Table XXIX, Appendix B.

**Observations taken at three selected locations - 6 cm from top, and bottom and center positions.

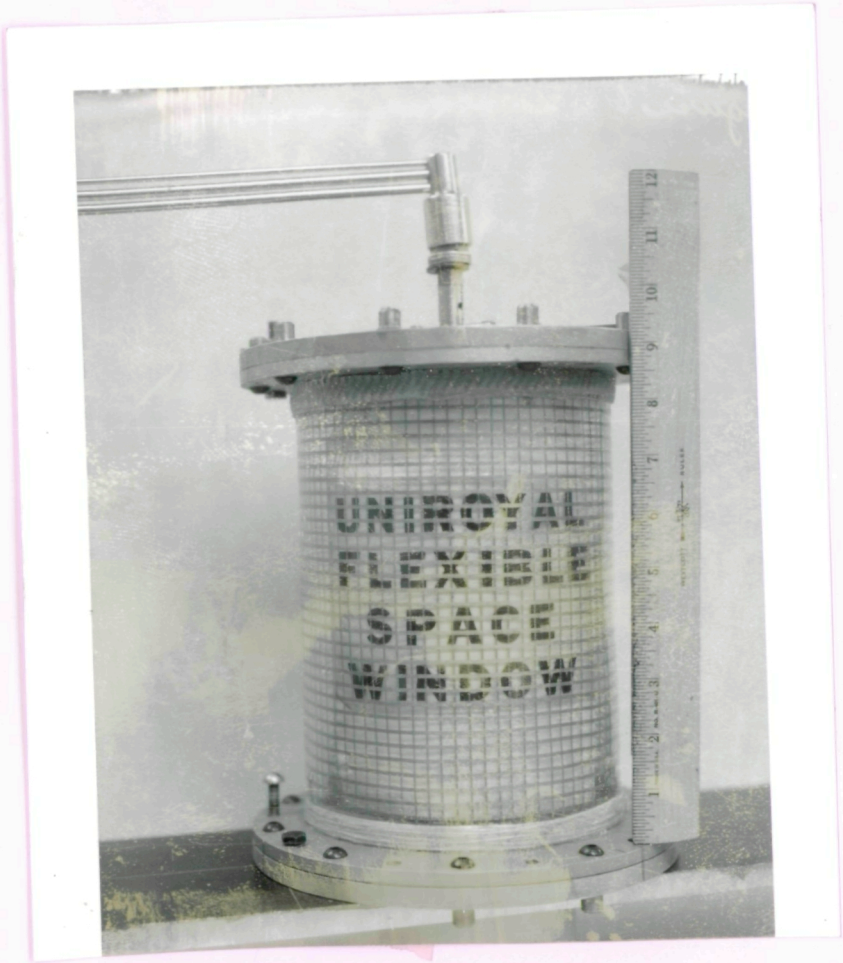



FIGURE 6

PHASE I - FLEXIBLE WINDOW
(15.2 cm diameter by 20.3 cm long)
BEFORE COLLAPSING

FIGURE 7

PHASE I - FLEXIBLE WINDOW
(15.2 cm diameter by 20.3 cm long)
IN COLLAPSED STATE (FIRST CYCLE)

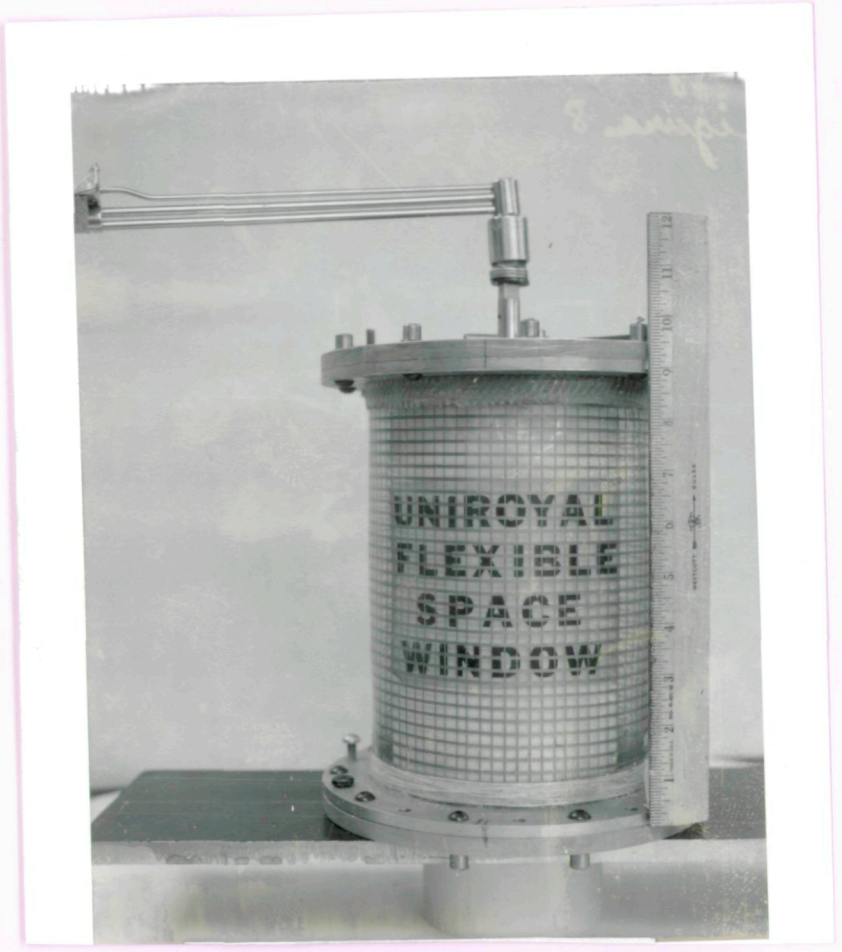



FIGURE 8

PHASE I - FLEXIBLE WINDOW
(15.2 cm diameter by 20.3 cm long)
IN FREE STATE AFTER ONE CYCLE
OF COLLAPSE/EXTENSION

the axial reinforcement at an angle (See Data Table XXX, Appendix B). However, this could not be attributed entirely to the effect of reinforcement angle alone, since other variables such as variation in window composite thickness, possible variations in their inherent properties, introduced during individual window fabrication, and the accuracy of the measurements determined by measuring tools, may be partially responsible.

B. Optical Transparency

1. Evaluation Program

The most important acceptance criteria for the reinforced window composite is visibility through the viewing area. In order to determine the effect of reinforcement angles on visibility of window composite, the Human Factor Optical Test, developed under NASA Contract NASI-7771 (Ref. 2) was conducted on reinforced cylindrical windows containing the same reinforcement material and pattern but different axial wire angles. Each cylindrical window tested had groups of two wires (R-1) type, see Table XI) in axial direction and groups of four wires in girth direction equally spaced at a distance of 0.63 cm in both directions.

2. Human Factors Optical Test

The Human Factor Optical Test is a comparative evaluation of the optical clarity of reinforced composite. In this test, the viewer attempts to focus through the window on the eye chart characters as in Table XIII. In cylindrical windows, the eye chart (Figure 9) was placed inside the window at a distance of 6.35 cm from the optimum curvature. Observations were made at various distances from the window and then overall qualities of the reinforced window were rated according to the factors listed in Table XIV.

## TABLE XIII

### EYE CHART CHARACTERS USED IN HUMAN FACTORS OPTICAL TEST

| Number Sequence | Print Size (mm) | Print Size Inch |
|---|---|---|
| 0695 | 6.350 | 32/128 |
| 3860 | 4.762 | 24/128 |
| 2439 | 3.968 | 20/128 |
| 8307 | 2.381 | 12/128 |
| 6379 | 1.785 | 9/128 |
| 7860 | 1.190 | 6/128 |

## TABLE XIV

### HUMAN FACTORS OPTICAL TEST RATING PLAN USED IN CYLINDRICAL WINDOWS

| A. Blurriness (distortion) | B. Ability to Focus | C. Readibility (last clear number) |
|---|---|---|
| *1. No distortion | *1. Eye focus immediately | *1. Reading clear - minimum of magnification disturbance |
| 2. | 2. | 2. |
| 3. Blurred but still comfortable | 3. Strands change focus but still comfortable | 3. Letters change magnification but still comfortable |
| 4. | 4. | 4. |
| 5. Highly distorted, uncomfortable | 5. Strands interfere with focusing | 5. High degree of magnification change (reading moves with eye movement) |
| Record last legible number | Record last legible number | Record last legible number |

*Equivalent to reference of no window present.

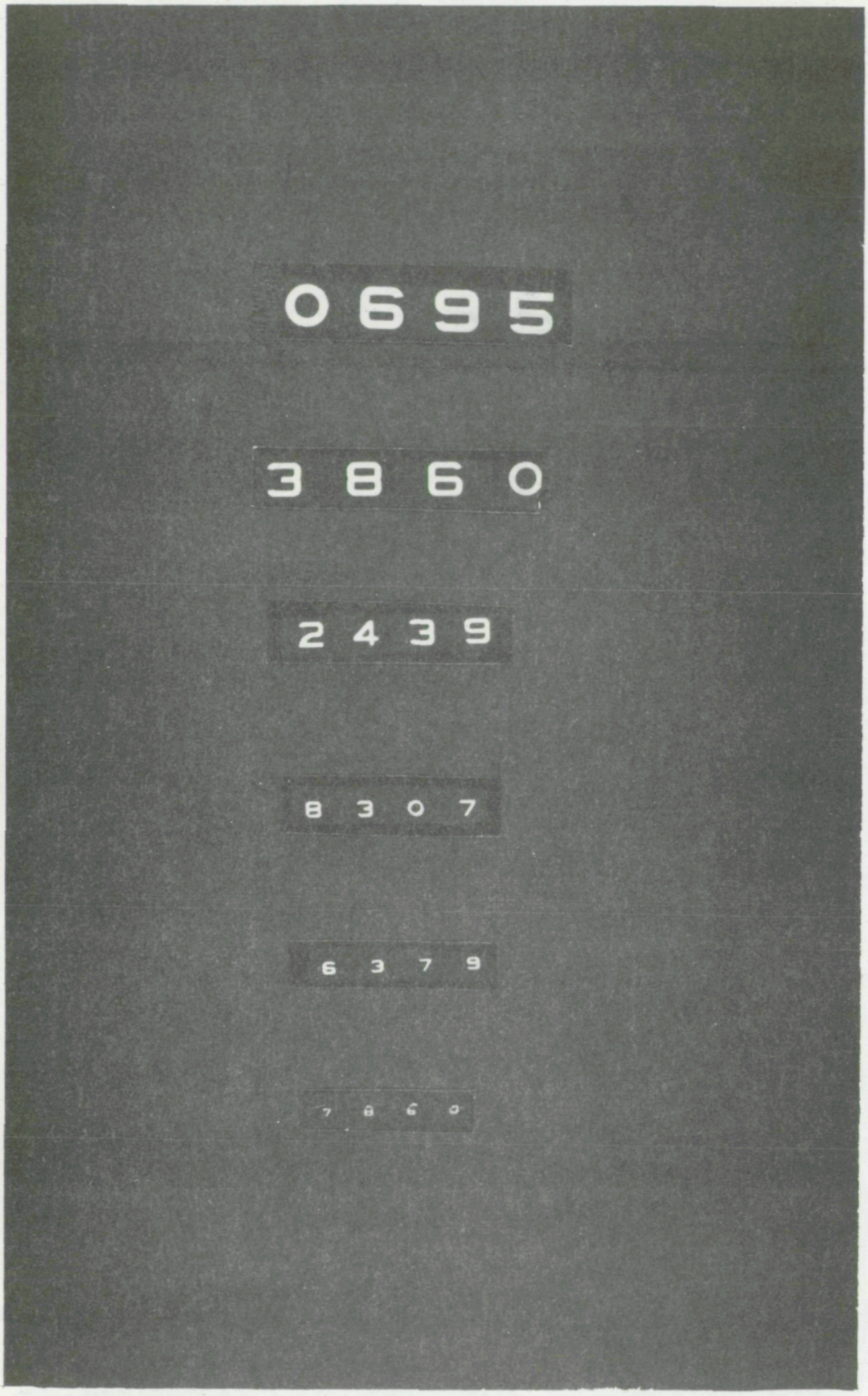



FIGURE 9

HUMAN FACTORS EYE CHART

3. Effect of Reinforcement Angles on Optical Transparency

A Human Factors Optical test was conducted on four windows. Windows #US-10 and US-19 had axial reinforcement members parallel to cylindrical window axis ($0^{o}$ angle), whereas windows #US-17 and US-20 had axial reinforcement members at an angle of $7^{o}$ and $15^{o}$ respectively.

Tests on these windows were conducted after subjecting the windows to 10 cycles of collapse/extension and then 24 hours in a collapsed state, and also when internally pressurized to 3.47 nscm, 6.943 nscm and 10.413 nscm.

Test results are tabulated in Table XV. According to the Human Factors Optical test rating program, the windows with their reinforcement member parallel to the cylindrical window axis ($0^{o}$ angle) were preferred over the windows with their reinforcement members at an angle.

During the optical transparency evaluation, it was felt that the overlapping of straight reinforcement members falling directly on the straight written eye chart characters was slightly more prominent in windows with $0^{o}$ reinforcement angle as compared to windows with $7^{o}$ or $15^{o}$ reinforcement angles. However, the undesirable psychological effect on viewing through the inclined reinforcement members could not entirely be neglected.

Figure 10 shows the window with straight reinforcement members, whereas Figure 11 shows the reinforcement at an angle of $15^{o}$.

Figure 12 shows the window containing straight axial reinforcements (no angle) with "Human Factors Eye Chart" inside.

C. Pressure Testing of Phase I Subscale Cylindrical Windows

Three optically transparent subscale cylindrical windows (each 15.2 cm diameter by 20.3 cm long) were fabricated using axial reinforcements at

FIGURE 10

PHASE I - FLEXIBLE WINDOW
(15.2 cm diameter by 20.3 cm long)
WITH AXIAL REINFORCEMENT MEMBERS
(R-1) AT 0 DEGREES ANGLE

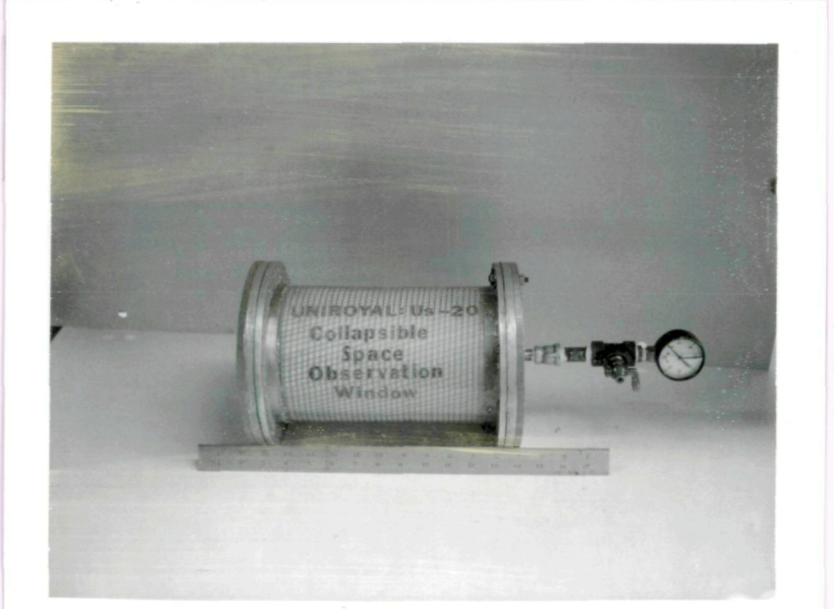



FIGURE 11

PHASE I - FLEXIBLE WINDOW
(15.2 cm diameter by 20.3 cm long)
WITH AXIAL REINFORCEMENT MEMBERS
(R-1) AT 15 DEGREES ANGLE

FIGURE 12

PHASE I - FLEXIBLE WINDOW
(15.2 cm diameter by 20.3 cm long)
WITH HUMAN FACTORS EYE CHART INSIDE
FOR OPTICAL TRANSPARENCY TEST

TABLE XV

HUMAN FACTORS OPTICAL TESTS FOR PHASE I
WINDOWS CONTAINING AXIAL WIRES AT ANGLES

| Window No. | Axial Wire Angle | Eye Distance From Window (cm) | Human Factors | Rating | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Original | After 10 Cycles of Collapse/ Extension Cycles and 24 Hrs. in Collapsed Condition | Pressurized To 3.471 nscm | Pressurized To 6.948 nscm | Pressurized To 10.413 nscm |
| US-10* | 0° | 25. | A | 1 | 1 | 1 | 1 | 1 |
| | | | B | 1.5 | 2 | 1.5 | 2 | 2 |
| | | | C | 1 | 2 | 1 | 1 | 1 |
| | | | Last Leg. No. | 7860 | 7860 | 7860 | 7860 | 7860 |
| | | 50. | A | 1 | 1 | 1 | 1 | 1 |
| | | | B | 2 | 2 | 2 | 2 | 2 |
| | | | C | 1 | 2 | 1 | 1 | 2 |
| | | | Last Leg. No. | 7860 | 7860 | 7860 | 7860 | 7860 |
| | | 100 | A | 1 | 1.5 | 1 | 1 | 1 |
| | | | B | 2 | 3 | 2 | 2 | 2 |
| | | | C | 2 | 2 | 2 | 2 | 2 |
| | | | Last Leg. No. | 6379 | 6379 | 6379 | 6379 | 6379 |
| US-19 | 0° | 25. | A | 1 | 1 | 1 | 1 | 1 |
| | | | B | 2 | 2 | 2 | 2 | 2 |
| | | | C | 1.5 | 2 | 1.5 | 1.5 | 1.5 |
| | | | Last Leg. No. | 7860 | 7860 | 7860 | 7860 | 7860 |
| | | 50. | A | 1 | 1 | 1 | 1 | 1 |
| | | | B | 2 | 3 | 2 | 2 | 2 |
| | | | C | 2 | 2 | 2 | 2 | 2 |
| | | | Last Leg. No. | 7860 | 7860 | 7860 | 7860 | |
| | | 100 | A | 1 | 1.5 | 1 | 1 | 1 |
| | | | B | 2 | 3 | 2 | 2 | 2 |
| | | | C | 2 | 2 | 1 | 2 | 2 |
| | | | Last Leg. No. | 6379 | 6379 | 6379 | 6379 | 6379 |

*Window #US-10 remained in collapsed condition for 40 hours instead of 24 hours.

TABLE XV (Cont'd.)

HUMAN FACTORS OPTICAL TESTS FOR PHASE I
WINDOWS CONTAINING AXIAL WIRES AT ANGLES

| Window No. | Axial Wire Angle | Eye Distance From Window (cm) | Human Factors | Rating: Original | Rating: After 10 Cycles of Collapse/ Extension Cycles and 24 Hrs. in Collapsed Condition | Rating: Pressurized To 3.471 nscm | Rating: Pressurized To 6.948 nscm | Rating: Pressurized To 10.413 nscm |
|---|---|---|---|---|---|---|---|---|
| US-17 | 7° | 25. | A | 2 | 2 | | 2 | 2 |
| | | | B | 2 | 2 | | 2 | 2 |
| | | | C | 2 | 2 | | 2 | 2 |
| | | | Last Leg. No. | 7860 | 7860 | | 7860 | 7860 |
| | | 50. | A | 2 | 2 | | 2 | 2 |
| | | | B | 2 | 2 | | 2 | 2 |
| | | | C | 2 | 2 | | 2 | 2 |
| | | | Last Leg. No. | 6379 | 7860 | | 6379 | 6379 |
| | | 100 | A | 2 | 2 | | 2 | 2 |
| | | | B | 3 | 3 | | | |
| | | | C | 2 | 2 | | 3 | 2 |
| | | | Last Leg. No. | 6379 | 6379 | | 6379 | 6379 |
| US-20 | 15° | 25. | A | 1 | 1 | | | |
| | | | B | 2 | 2 | | | |
| | | | C | 2 | 2 | | | |
| | | | Last Leg. No. | 7860 | 7860 | | | |
| | | 50. | A | 1 | 2 | | | |
| | | | B | 2 | 3 | | | |
| | | | C | 2 | 2 | | | |
| | | | Last Leg. No. | 7860 | 7860 | | | |
| | | 100 | A | 1 | 2 | | | |
| | | | B | 3 | 3 | | | |
| | | | C | 2 | 3 | | | |
| | | | Last Leg. No. | 6379 | 8307 | | | |

three different angles - $0^0$, $7^0$ and $15^0$. Each window was attached to window fittings. Closure plates with airtight seals and air pressure gauge were installed before testing. Two types of pressure tests were conducted on each window at room temperature:

1. Low pressure - 10.413 nscm (15.0 psig) test for long period (24 hours or more)
2. Gradually increased high pressure - 41.65 nscm (60.0 psig) for short period.

One window having axial reinforcement at $15^0$ was also tested for blowout strength. The results of each subscale unit tested are summarized in Table XVI.

Test results showed that window #US-10 had no drop in pressure, whereas windows #US-17 and US-20 had 0.96% and 0.59% pressure drop from original pressure of 10.41 nscm in 24 hours. Window #US-17, when held for 64 hours under 10.41 nscm pressure, had a loss in pressure of only 1.23%.

It was theorized that the slight pressure drop indicated by the pressure gauge was mainly due to change in the window volume/atmospheric conditions rather than to any leakage through the flexible window wall composite or fittings. High pressure tests indicated no leakage up to a test pressure of 41.66 nscm. The blowout strength test conducted on all three windows (three angles) exceeded the required level of 40.8 nscm. When window #US-20 was internally air pressurized, the burst pressure recorded was 49.99 nscm and the failure occurred only in the loop wires attached to the fittings. This indicated that the window wall composite was capable of withstanding the rigors of high pressure. Additionally, windows under 10.413 nscm pressure exhibited no significant bulging in the flexible structure. Figures 13 and 14 show the flexible window with no air pressure and with 10.413 nscm internal air pressure respectively.

## SUMMARY TABLE XVI

### PRESSURE TESTS FOR PHASE I SUBSCALE FLEXIBLE CYLINDRICAL WINDOWS

| Window Code | US-10 | US-17 | US-20 |
|---|---|---|---|
| Axial Reinforcement Angle (degrees) | 0 | 7 | 15 |
| **LOW PRESSURE TEST** | | | |
| Initial Pressure (nscm) | 10.41 | 10.24 10.41 | 10.41 |
| Pressure Held for (hours) | 24 | 24 64 | 24 |
| Final Pressure (nscm) | 10.41 | 10.14 10.28 | 10.35 |
| Pressure Drop (nscm) | 0.00 | 0.10 0.13 | 0.06 |
| Remark: | Slight drop in pressure is anticipated due to change in window volume/atm. conditions. | | |
| **HIGH PRESSURE TEST** | | | |
| Required Blowout Strength | 40.8 nscm | 40.8 nscm | 40.8 nscm |
| Initial Pressure (nscm) | 3.47 10.41 20.83 31.24 41.66 | 3.47 10.41 20.83 31.24 41.66 | 3.47 10.41 20.83 31.24 41.66 |
| Pressure Held for (min.) | 1 1 1 1 3 | 2 1 1 1 3 | 2 1 1 1 3 |
| Final Pressure (nscm) | 3.47 10.41 20.83 31.24 41.66 | 3.47 10.41 20.83 31.24 41.66 | 3.47 10.41 20.83 31.24 41.66 |
| Pressure Drop (nscm) | 0 0 0 0 0 | 0 0 0 0 0 | 0 0 0 0 0 |
| Bursting Pressure (nscm) | - | - | 49.99 |
| Remark: | Exceeded required blowout strength. For safety reasons, no visual examination for bulging was conducted at high pressure. | | Window burst at the bottom, breaking only the loop wires. No damage to the body of the window. |

FIGURE 13

PHASE I - FLEXIBLE WINDOW
(15.2 cm diameter by 20.3 cm long)
WITH NO INTERNAL AIR PRESSURE

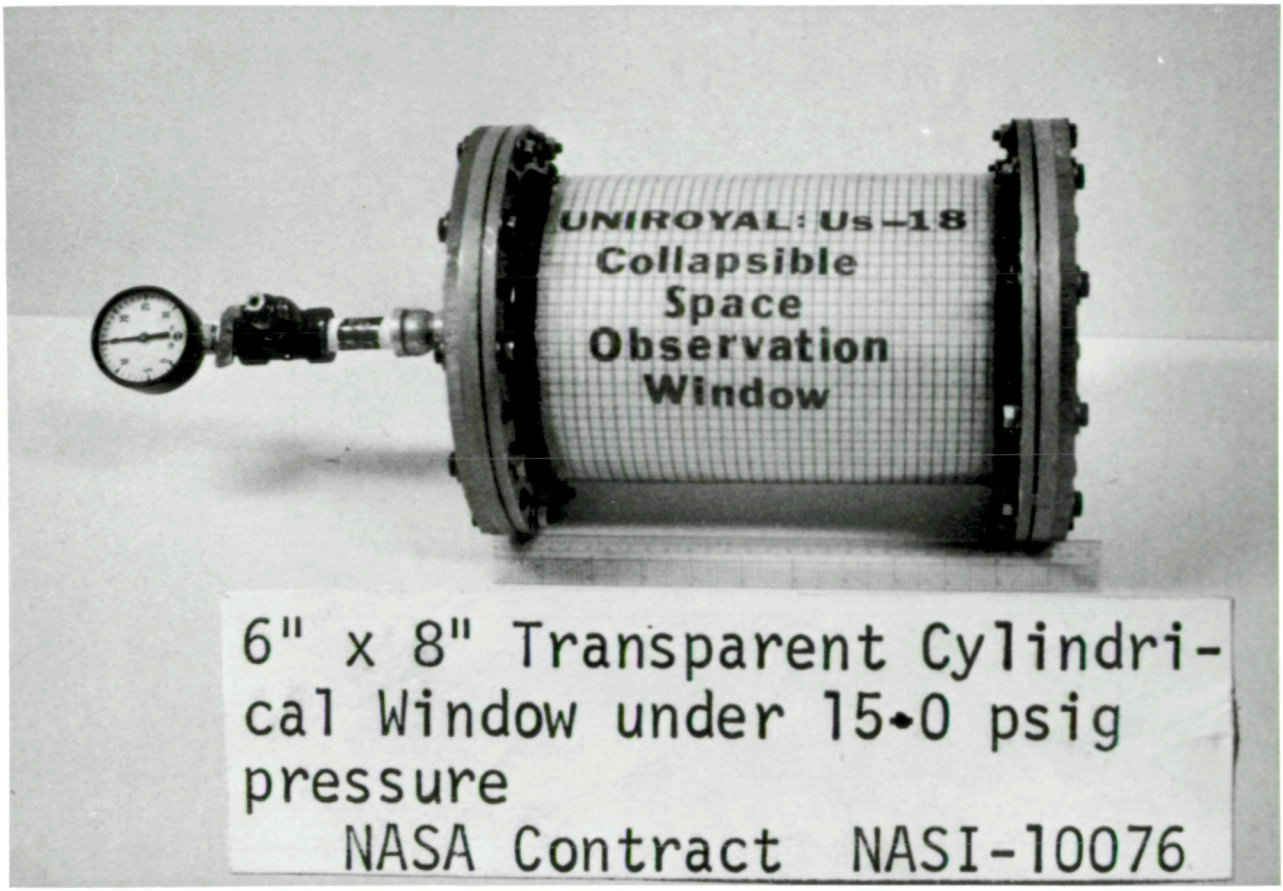



FIGURE 14

PHASE I - FLEXIBLE WINDOW
(15.2 cm diameter by 20.3 cm long)
UNDER 10.413 NSCM (15.0 psig)
AIR PRESSURE

D. Flex and Peel Bond Strength Tests

Window fabrication technique involved the vacuum casting of liquid urethane polymer (Conathane EN-1554) film on cured urethane (Conathane EN-1554) film preapplied to the male-section of the mold. This suggested the determination of bonding characteristics of urethane to urethane film (without any use of adhesive) and also the possibility of film delamination when the window undergoes collapse/entension cycles.

Test specimens were prepared by casting urethane film (Conathane EN-1554) on the surface of a cured urethane film (Conathane EN-1554). Strips of 2.50 cm width were cut from the film lamina and then tested for peel bond strength on a pendulum type strength tester. Unbonded portions of cut strips were clamped in the jaws and then pulled apart ($180^{o}$) the two bonded layers of the lamina. Strength was recorded as peel bond strength (see Table XVII).

A DeMattia flex test was conducted on the reinforced window composite and also on an unreinforced lamina. Cut strips of 2.54 cm width were given one complete twist ($180^{o}$) and then flexed for 100,000 cycles. Deterioriation in the test samples were visually examined.

Test results are summarized in Table XVII.

TABLE XVII

PHASE I

DEMATTIA FLEX AND PEEL BOND STRENGTH TEST RESULTS - URETHANE COMPOSITE ONLY

| Flex Test* | Nonreinforced Urethane Laminae | | | | | | Wire Reinforced Urethane Composite | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Specimen No. | 1 | 2 | 3 | 4 | 5 | 6 | 1 | 2 | 3 | 4 | 5 |
| Size (cm) | 2.5x20 | 2.5x20 | 2.5x20 | 2.5x20 | 2.5x20 | 2.5x20 | 2.5x20 | 2.5x20 | 2.5x20 | 2.5x20 | 2.5x20 |
| Effective Specimen Size(cm) | 2.5x9 | 2.5x9 | 2.5x9 | 2.5x9 | 2.5x9 | 2.5x9 | 2.5x9 | 2.5x9 | 2.5x9 | 2.5x9 | 2.5x9 |
| Total Thickness (mm) | 3.48 | 3.48 | 3.45 | 3.40 | 3.38 | 3.38 | 2.64 | 2.59 | 2.59 | 2.59 | 2.62 |
| Twist Inserted (degrees) | 180 | 180 | 180 | 180 | 180 | 180 | 180 | 180 | 180 | 180 | 180 |
| Total No. of Cycles Flexed x 1000 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Results | | | | | | | | | | | |
| Crack | No | No | No | No | No | No | No | No | No | No | No |
| Delamination | No | No | No | No | No | No | No | No | No | No | No |
| Peel Bond Strength Test | Film's layers could not be separated in any of the specimens. Bond strength greater than film breaking strength. | | | | | | | | | | |

*See Appendix A for Test Method

## RESULTS OF REINFORCEMENT ANGLES EVALUATION

Collapse/extension cycle tests conducted on flexible windows having three different reinforcement angles indicated that the cylindrical windows with no angle (0 degree) in the axial reinforcement members could as easily be collapsed as other windows with axial reinforcement members at an angle of 7 degrees or 15 degrees. The maximum torque-ranges needed to collapse the windows during the first cycle were 140-75 (in-lb) for window #US-10 with no angle in the axial reinforcement, while 170 - 110 (in-lb) was required for window #US-17 (with axial reinforcements at 7 degrees) and 170-80 for window #US-20 having reinforcements at 15 degrees angle (see Table XXX, Appendix B).

No major dimensional changes under 10.413 nscm pressure were noticed in the cylindrical windows having reinforcement members at different angles (see Tables XXIX and XXX, Appendix B).

Material degradation due to the collapse/extension cycles was not directly the result of different reinforcement angles but were largely dependent upon the fabrication technique involved in the construction of the individual windows and the inherent properties of the matrix polymer itself.

Human Factors Optical Test results were favorable to straight axial winding (0 degree angle) rather than axial reinforcements at an angle. Additionally, the adverse psychological effect on viewing through the window composite reinforced with wires at an angle was a factor which could not entirely be overlooked.

Ease in the fitting attachment to straight protruded loop wires of the window and higher load carrying ability of axial reinforcements under tension were also factors favorable in the selection of 0 degree reinforcement angle. See Table X for tension developed in reinforcements at various angles under pressure.

## CONCLUSIONS FROM PHASE I STUDY

Fabrication and evaluation of subscale cylindrical windows during the Phase I program established several parameters necessary for the fabrication of larger size flexible windows (45.7 cm diameter by 61.0 long) in Phase II of this program. The following are the conclusions drawn from Phase I study:

1. A flexible cylindrical observation window can be fabricated which can be collapsed to at least one-sixth of its original length by means of mechanical force.
2. It is not essential to introduce a reinforcement member at an angle in order to collapse the window upon itself by twisting. Cylindrical windows containing axial reinforcement members parallel to the cylinder axis can be easily collapsed.
3. The most promising method of reinforcement embedment is the combination of applied film to the male-section mold and then vacuum encapsulating the outer layer to cover the entire reinforcement surface.
4. Window wall composites reinforced with high strength steel wire can meet the strength requirements.
5. Use of flame retardant evaluated in this program did not show any synergistic improvement in the reduction of the flammability hazard of the composite material.
6. A flexible cylindrical window can be attached to a rigid fitting for installation in the space structures.

## PHASE II TASKS

Phase II of this NASA Contract NASI-10076 covered the work required for producing and incorporating a nominal 45.7 cm diameter cylindrical flexible window into a fixture designed to simulate the wall of a flexible space vehicle. Physical and mechanical test evaluation were conducted on this model. A prototype flexible cylindrical window, US.L-5, attached to fittings and equipped with a retraction system, was also sent to the National Aeronautics and Space Administration, Langley Research Center, for further evaluation and verification of the concept.

# PHASE II PROTOTYPE FABRICATION AND EVALUATION

## Design Parameters

Design parameters selected for the fabrication of flexible transparent window (45.7 cm diameter by 61.0 cm long) were those evolved from the Phase I development program.

The basic method of reinforcement embedment developed in the Phase I program was employed. The window fabrication system was slightly modified, however, due to certain scale-up problems not encountered during the Phase I evaluation program. The main problem encountered during the fabrication of Phase II windows was in the vacuum encapsulation of the window. Unfilled sections of the vac-mold chamber and pockmarks in the outer layer of window composites resulted in several modifications to the fabrication system.

The most promising system used to fabricate cylindrical window, US.L-5, with black coated wire reinforcement, was as shown in Figure 16. One window, US. L-4, was tested in-house to demonstrate the collapsible window concept. Another was used to establish silicone application technique.

## PHASE II WINDOW COMPOSITE MATERIALS

On the basis of Phase I test results, windows fabricated consisted of the following materials:

1. Conathane EN-1554 as the optically transparent matrix polymer (polyether urethane).
2. Conap AD-1146 adhesive for joining the edges of two preapplied films.
3. Chemlok 607 as the adhesive for bonding the silicone "barrier film" to the urethane surface (Conathane EN-1554).
4. Sylgard 184 (RTV silicone) used inside and outside of cylindrical window as a barrier film.
5. Brass plated steel wire (R-1) as the reinforcement in windows US.L-3 and US.L-4 and black coated carbon rocket wire (R-2) as the reinforcement in window US.L-5.

No flame retardant was used in any of Phase II windows.

## PHASE II URETHANE POLYMER FORMULATION FOR VACUUM ENCAPSULATION

For fabrication of all transparent windows in Phase I and Phase II, the following basic formulation was used. However, for films used in flame retardant evaluation, a slight change in the formulation was made due to necessary additives.

| Ingredients | Amount (gm) |
|---|---|
| Conathane EN-1554 - Part A | 300.00 |
| Toluol (dry) | 50.00 |
| Conathane EN-1554 - Part B | 100.00 |
| Total | 450.00 |

It was observed that the use of methyl ethyl ketone (MEK) solvent in place of toluol in casting the films produced an "orange peel" effect which was undesirable for the transparent window application. As the relative evaporation rate* (Ref. 6) of MEK (4.6 on the basis of n-butyl acetate = 1) was much higher than toluol evaporation (2.1 on the basis of n-butyl acetate), use of toluol in all the film casting was preferred.

*It is an empirical expression of the rate of escape of vapor from a liquid. Evaporation rates of various solvents are compared to the evaporation rate of n-butyl acetate or carbon tetrachloride. MEK will evaporate from a non-porous surface 2.2 times faster than toluol.

## URETHANE FILM CASTING FOR PHASE II WINDOWS

During the Phase II program twenty urethane films (Conathane EN-1554) were cast on a silicone film (Sylgard 184) surface adhered to a glass plate. Every effort was made to maintain a 1.00 mm to 1.14 mm film thickness. For window fabrications, two clear films were joined together using Conap AD-1146 adhesive. The joined films were cut to the size of the male-section mold circumference and then applied to the surface.

Each urethane film cast was of approximately 66 cm by 81 cm dimensions.

## DULL BLACK COATING ON STEEL WIRE REINFORCEMENT

During the previous flexible window evaluation program, brass coated steel wires were used as reinforcement members. Since the optical clarity one obtains in looking through a window is not only dependent on the amount of light which is transmitted, but is also influenced by the degree of resolution provided by the window, it was essential to give black coating to steel wire reinforcement to reduce reflection.

During previous work (Ref. 2), attempts were made to black coat the brass plated wires using an adhesive system, but this was not satisfactory for several reasons:

1. Increase in the diameter of the reinforcement member.
2. The coating material did not adhere firmly to the surface of reinforcement and flaked-off during winding.
3. Variation in reinforcement diameter.

In the current development work, a new approach was adopted to blacken the brass plated carbon rocket wire. The process used was the Ebonol "C" Process* which involved the direct oxidation at low temperatures of copper and copper alloys to form black, adherent cupric oxide. The main advantages in this black coating were:

1. Unlike sulphide black coatings, Ebonol "C" finishes were stable and did not tend to recrystallize ("spot out").
2. Extremely stable chemically and physically (THF and MEK solvents had no effect) and so no flaking-off during winding.
3. Very uniform coating and practically no increase in diameter and good adhesion with urethane.

*Patented process developed by Enthone, Inc., New Haven, Conn. Black coating on brass plated wire was done by Swanson Plating Co., South Bend, Indiana, for the contractor.

## PHASE II NETTING PATTERN DESIGN PARAMETER

Based upon the information obtained from the Phase I window evaluation program, all Phase II windows were fabricated with an orthogonal reinforcement pattern. The number of reinforcement members in axial and girth directions were as follows:

TABLE XVIII

| Window Trial No. | Window Code No. | Reinforcement Material | Total No. of Axial Wires/ 5 cm | Total No. of Girth Wires/ 5 cm |
|---|---|---|---|---|
| 1 | US.L-1 | R-1, Brass Plated wire cable - 0.3429 mm diameter | 24 in groups of 3 ends | 40 in groups of 5 ends |
| 2 | US.L-2 | R-1, Brass Plated wire cable - 0.3429 mm diameter | " | " |
| 3 | US.L-3 | " | " | " |
| 4 | US.L-4 | " | " | " |
| 5 | US.L-5 | R-2, Black Coated rocket wire cord - .254 mm diameter | 32*in groups of 4 ends | 40 in groups of 5 ends |

*Use of 4 end groups in the axial direction, provided each loop (for window attachment to fitting) having two wire ends and thus uniform loop strength throughout, whereas use of 3 end groups in the axial direction produced loops having 2 ends and one end alternately.

One window (US.L-5) fabricated under the Phase II program had the black coated carbon rocket wire as the reinforcement member. This window was sent to NASA for further evaluations.

Against a dark background, black coated wires were almost invisible.

## TOOLING FOR PHASE II WINDOW FABRICATION

Predicated upon the knowledge of the tooling designed for Phase I window evaluation, a vac-mold chamber for vacuum encapsulation was designed and fabricated to produce wire reinforced transparent cylindrical windows of 45.7 cm diameter by 61.0 cm long. The complete vac mold chamber assembly drawing is shown in Figure 15.

Closure plates to provide airtight seals to the top and bottom of the cylindrical window and two window-end fittings were also designed and fabricated as shown in Figure 23.

In order to demonstrate the concept of a flexible window capable of being collapsed upon itself through the application of a twisting force, a retraction system consisting of a collapsing rod with handle was also fabricated. The collapsing rod design was such that one end could easily be attached/detached to the top closure plate-notch developing a twisting pantographing motion as the cylinder was collapsed mechanically. Detailed drawings for pressure and collapsibility test setup are shown in Figure 24.

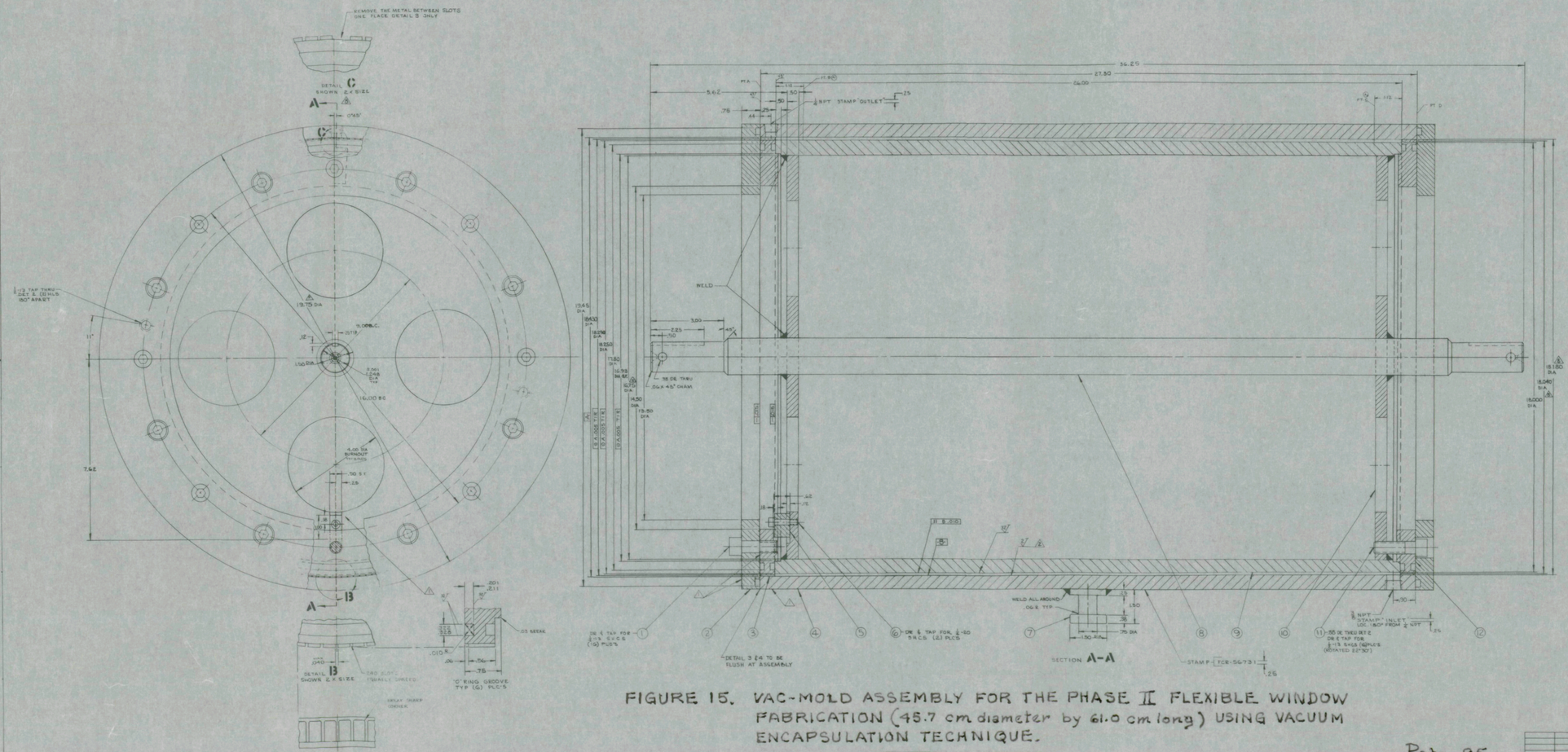



FIGURE 15. VAC-MOLD ASSEMBLY FOR THE PHASE II FLEXIBLE WINDOW FABRICATION (45.7 cm diameter by 61.0 cm long) USING VACUUM ENCAPSULATION TECHNIQUE.

FCR-56731 A

Page 85

## PHASE II WINDOW FABRICATION PROCEDURE

1. Application of Precast Film

The technique used in the fabrication of the Phase II prototype window was the combination of two techniques - film applied to mandrel and vacuum encapsulation as developed in the Phase I window fabrication program.

One coat of DC-55 silicone release agent was applied on the chromeplated male-section mold and then one layer of Mylar film (0.0254 mm thick) was wrapped around the male section mold surface. Precast films (see page 81) cut to male section mold size was applied firmly and longitudinal edges of the films were joined using Conap AD-1146 adhesive.

Axial wires were hand wound, whereas girth winding was done using a filament winding machine (see Table XVIII for netting pattern).

MS-122 (fluorocarbon release agent) was sprayed on only loop section wires and then the male and female sections of the mold were assembled. Before assembly, the inner surface of the female-section mold was coated with RAM-225 as a release agent and baked at 275$^{0}$ F for one hour.

The mold assembly was checked for any air leak and then the vacuum encapsulation process followed.

2. Vacuum Encapsulation

Preheated Conathane EN-1554 polymer with necessary additives was mixed and degassed thoroughly in the urethane pot. Air free urethane polymer was air pressurized to 3.47-4.86 nscm and fed into the bottom inlet of the assembled mold chamber while maintaining a vacuum of 735-760 mm Hg. in the upper portion of the vac mold chamber. When a solid stream of urethane started coming through the mold outlet (located at the top), the vacuum encapsulation process was terminated. The mold bottom inlet

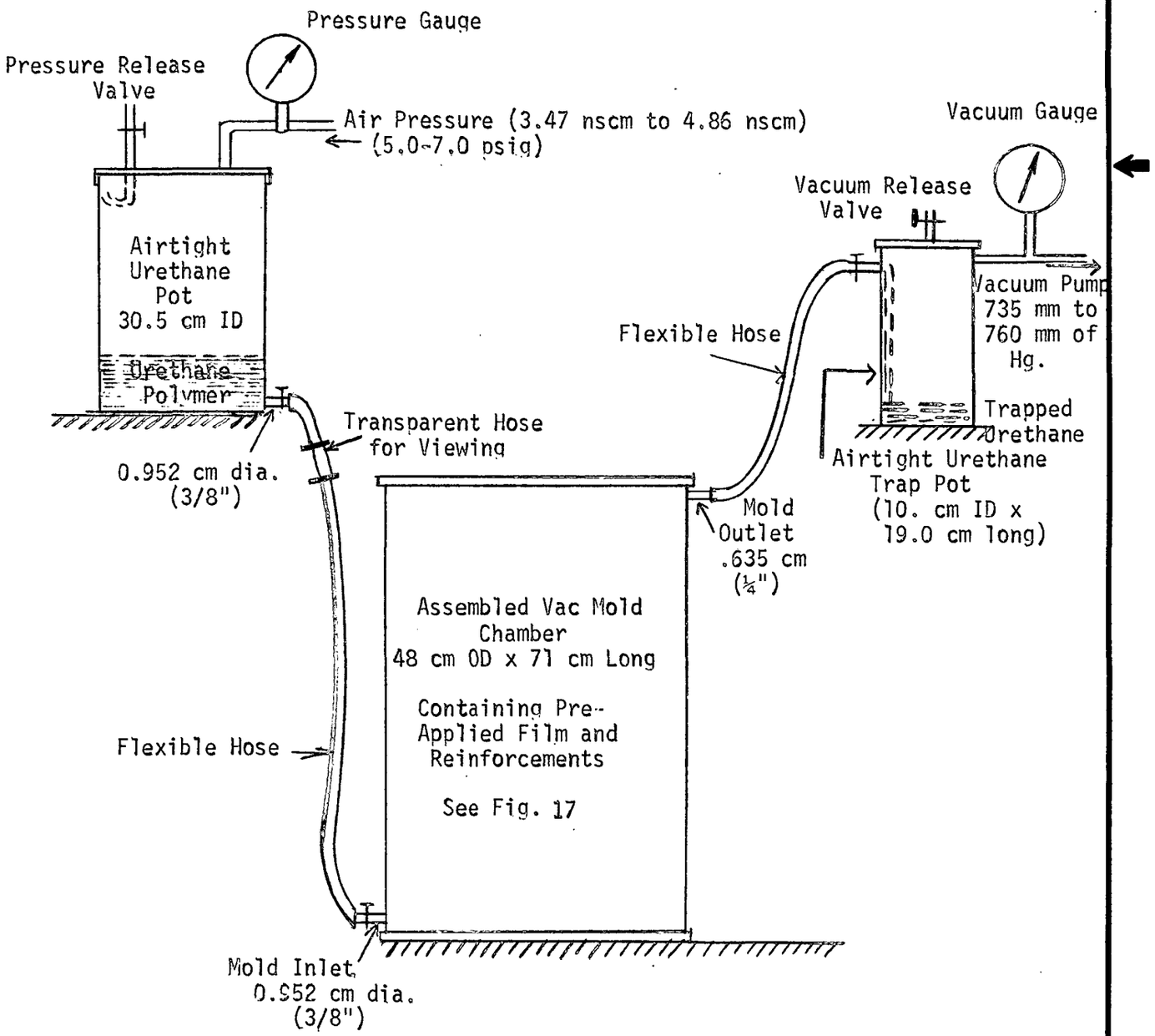
was closed at the termination of the process, while the mold outlet was left open for solvent escape during curing. The mold assembly was heated in an air circulating oven for 15-16 hours at 165$^{0}$ F to cure the cast film.

The female-section of the mold was disassembled first and then the window was removed from the male section mold easily because of a slight taper (approximately 0.53 degree) in the mold and the use of DC-55 release agent and Mylar film on the male-section of the mold.
The detailed description of window fabrication technique is shown in Figures 16 and 17.

3. Silicone Application

Fittings were attached to the window to facilitate mounting of the window on the filament winding equipment. Chemlok 607 adhesive was applied to the window surface* and then Sylgard 184 was poured on the inside and outside surfaces of the window. Excess silicone was removed and the window was kept rotating for about 15 hours at room temperature curing; post curing of the silicone was completed at 190$^{0}$ F for 1 hour in an oven.

*Window surfaces must be cleaned properly with methanol since Sylgard 184 silicone is very sensitive to contamination. It does not cure in the presence of materials containing free sulfur or amine, as experienced in this program.




PHASE II

FIGURE 16 FABRICATION SYSTEM FOR TRANSPARENT FLEXIBLE WINDOW (45.7 cm diameter by 61.0 cm long) USING COMBINATION OF PRE-APPLIED FILM AND VACUUM ENCAPSULATION

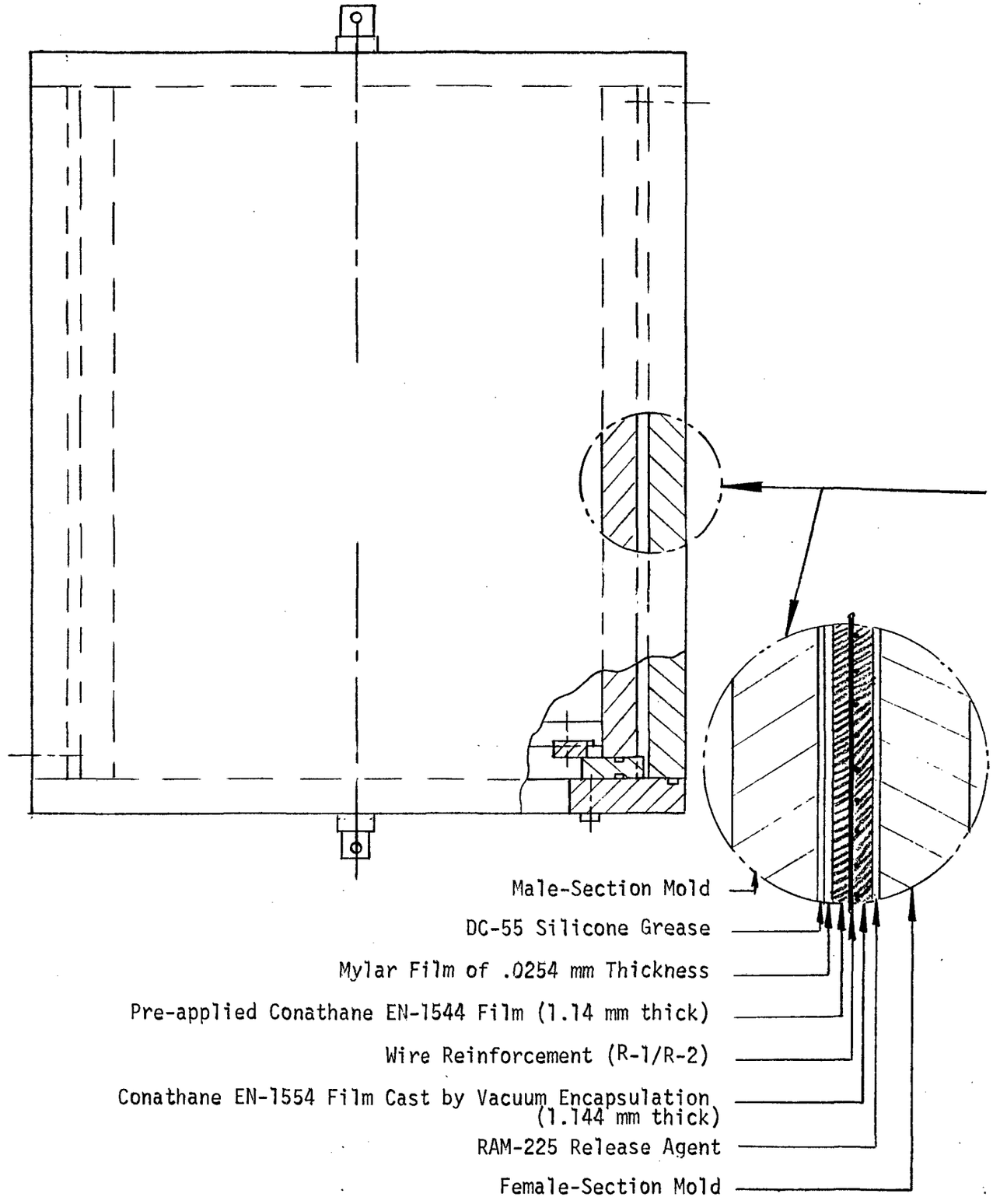



FIGURE 17 SECTIONAL VIEW OF VAC-MOLD CHAMBER AFTER CASTING PHASE II CYLINDRICAL WINDOW (45.7 cm diameter by 61.0 cm long)

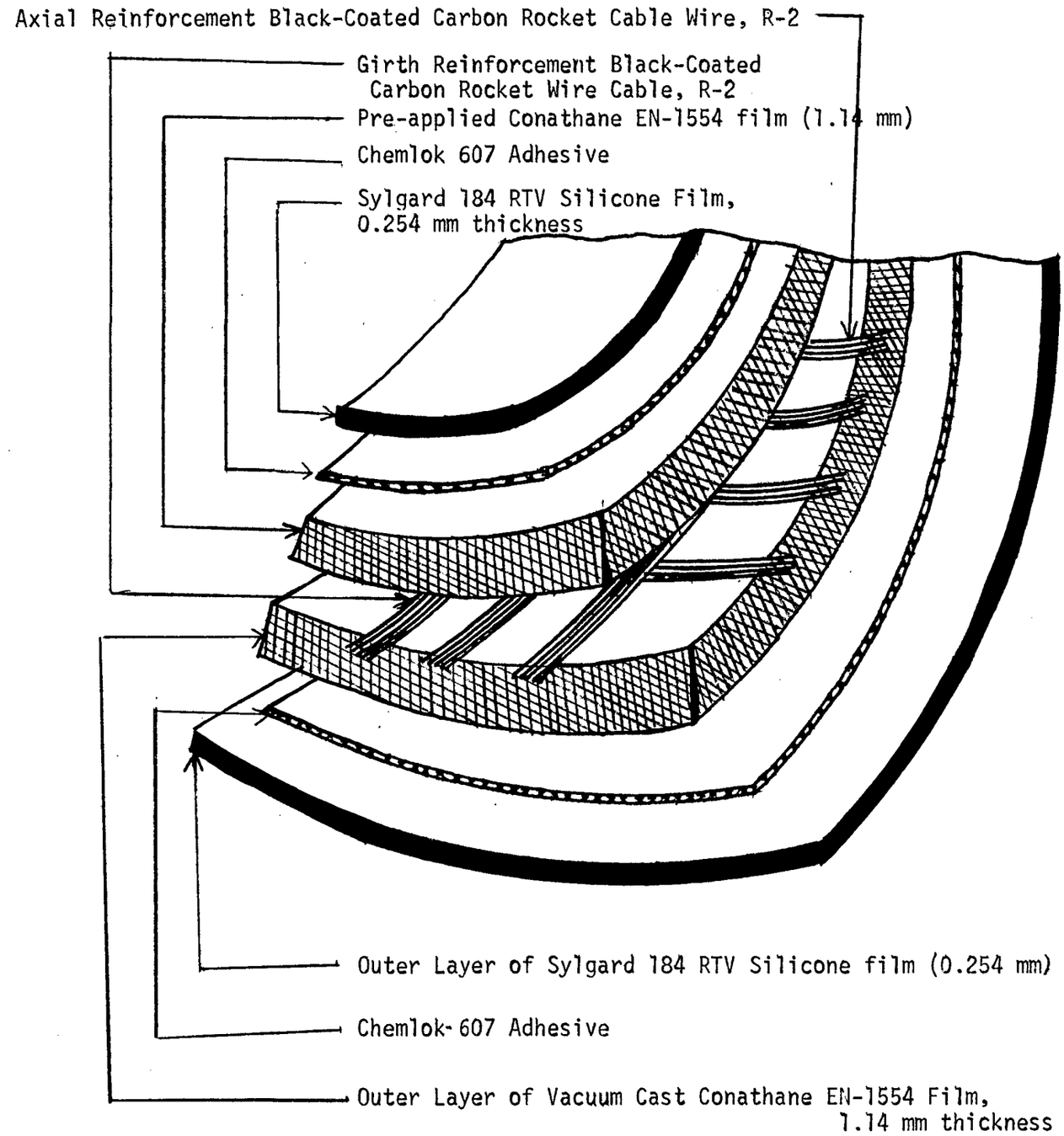



FIGURE 18 COMPOSITE WALL STRUCTURE OF A TYPICAL PHASE II COLLAPSIBLE OBSERVATION WINDOW (45.7 cm diameter by 61.0 cm long)

## PHASE II WINDOW FITTING ATTACHMENT

The incorporation of axial reinforcement member loops into the flexible window composite made it possible to improve and at the same time greatly simplify the attachment of fittings to the cylindrical flexible window.
The excellent adhesion characteristic of urethane not only to the fitting but the wire reinforcement, makes it possible to retain the window structure integtity when the window is subjected to internal pressure.
During the Phase I window evaluation program, a fitting attachment system was developed which involved the bonding of the window urethane to the fitting wall and keeping the reinforcement wire loops down against a circular end clamping ring. Difficulty was experienced in uniformly bonding the circumferential surface of the window to the circular fitting wall. The development of high stress concentration (under load), resulting from the sharp 90 degree change in direction of the loop wire reinforcement, was also undesirable.

In the Phase II window evaluation program, the fitting design and the fitting attachment system were modified to overcome the above mentioned problems. The outside diameter of the fitting wall was made slightly smaller than the inside diameter of the fabricated window, thus the window fit exactly on the fitting's wall. This eliminated any buckling of the window wall structure and the clamp was tightly wrapped around the window against the window wall (see Figure 19).

The changes in the loop wires direction were made through bearing of wire against a gradual radius of the metal restraining frame and hard epoxy. The window attachment system involved the embedding of loop wires permanently in the hard epoxy resin and simultaneously bonding epoxy resin to the fittings. This system eliminated any effect of slackness in the loop wires around the

metal "O" ring and also the loop wires were against a gradual radius of hard epoxy. The complete attachment system is shown in Figure 19.

Hard epoxy resin (Union Carbide ERL-2256/ZZLB 0820 in the ratio of 100/27.2 by weight) was initially selected and evaluated in Window No. US.L-4. The system worked well, as no sign of failure was observed in the composite structure, near the fitting wall, when internally pressurized up to 36.1 nscm. However, in the attachment of fittings to window No. US.L-5, the epoxy resin was changed to Shell Epon 828/DEH-14 for the following reasons:

1. *Shorter room temperature curing time as compared to Union Carbide ERL-2256/ZZLB 0820.
2. Better adhesion to window composite wall, reinforcements, and metal fitting surfaces.

*Epoxy ERL-2256/ZZLB 0820 did not cure in 48 hours for satisfactory handling, whereas Shell Epon 828/DEH-14 was cured in 24 hours at room temperature.

In order to provide an improved airtight seal around epoxy resin and provide a "cushion effect" for the circular metal clamping ring on the hard epoxy surface, liquid Vibrathane 6001 (a moisture-cure liquid polyester urethane produced by UNIROYAL's Chemical Division) was cast around and on the top of the cured epoxy ring.

The formulations used were as follows:

Epoxy

| Ingredients | Weight (gm) |
|---|---|
| Shell Epon 828 | 60.0 |
| DEH-14 | 40.0 |
| Total | 100.0 |

Polyester Liquid

| | | Weight (gm) |
|---|---|---|
| (A) | Vibrathane 6001 | 80.0 |
| | Methyl ethyl ketone | 20.0 |
| | Total | 100.0 |
| (B) | MOCA* | 50.0 |
| | Methyl ethyl ketone | 50.0 |
| | Total | 100.0 |

Mixing ratio A/B = $\frac{12.5}{1.0}$

*MOCA - A hindered, aromatic diamine curing agent for isocyanate-containing polymers. Its chemical composition is 4,4'-methylene-bis-(2-chloroaniline), and its solubility in methyl ethyl ketone solvent at 75° F is 51.0% by weight.

Liquid polyester urethane was allowed 24 hours at room temperature before handling.

A thin coat of Conap AD-1146 adhesive was applied on the fitting wall and inside the urethane surface of the window before installing the window structure against the circular fitting wall.

A hose clamp over the window wall composite against the fitting wall was tightened to prevent any possible separation of the window wall composite from the fitting wall.

A drawing of the fitting attachment system is shown in Figures 19 and 20.

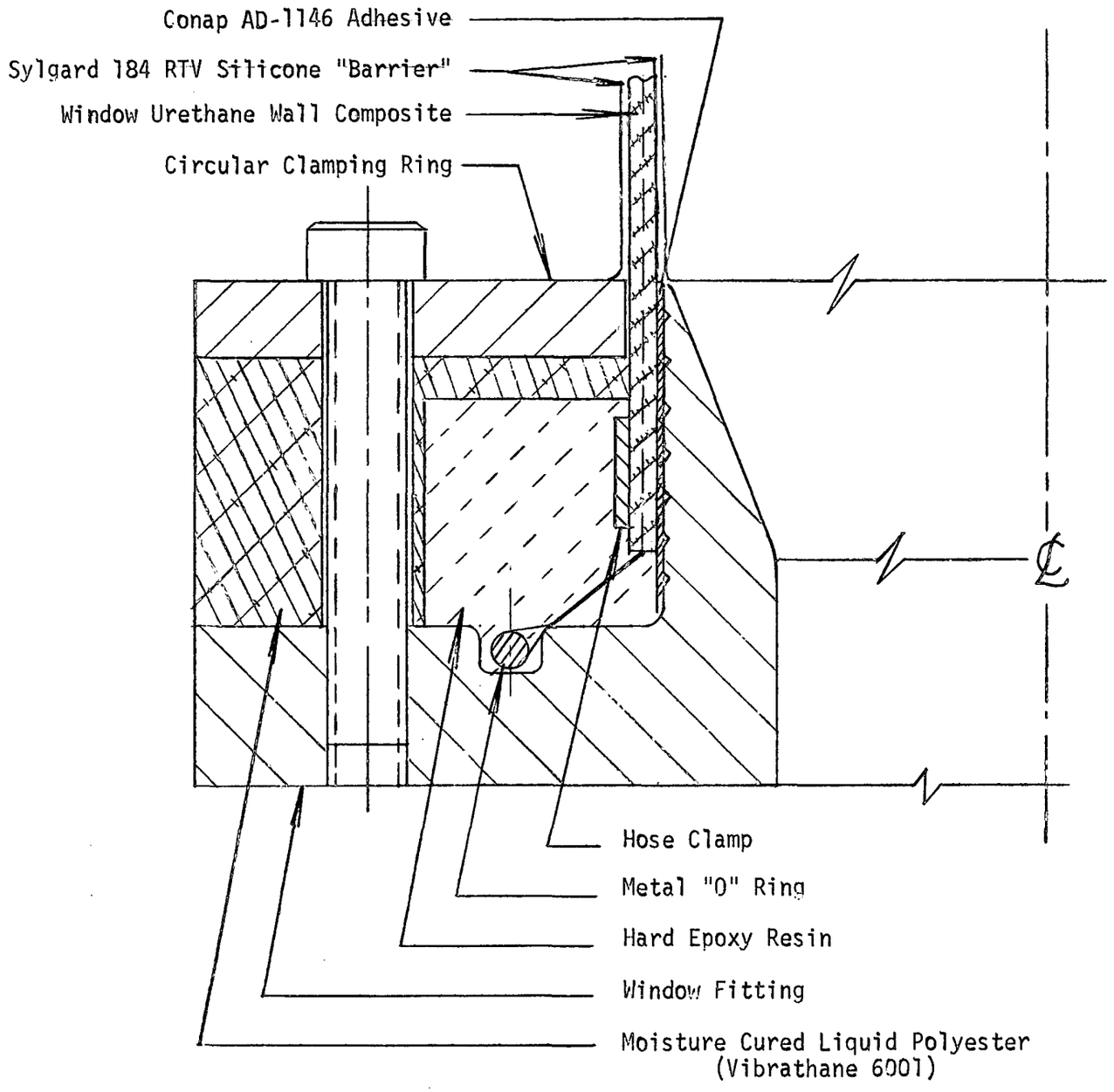
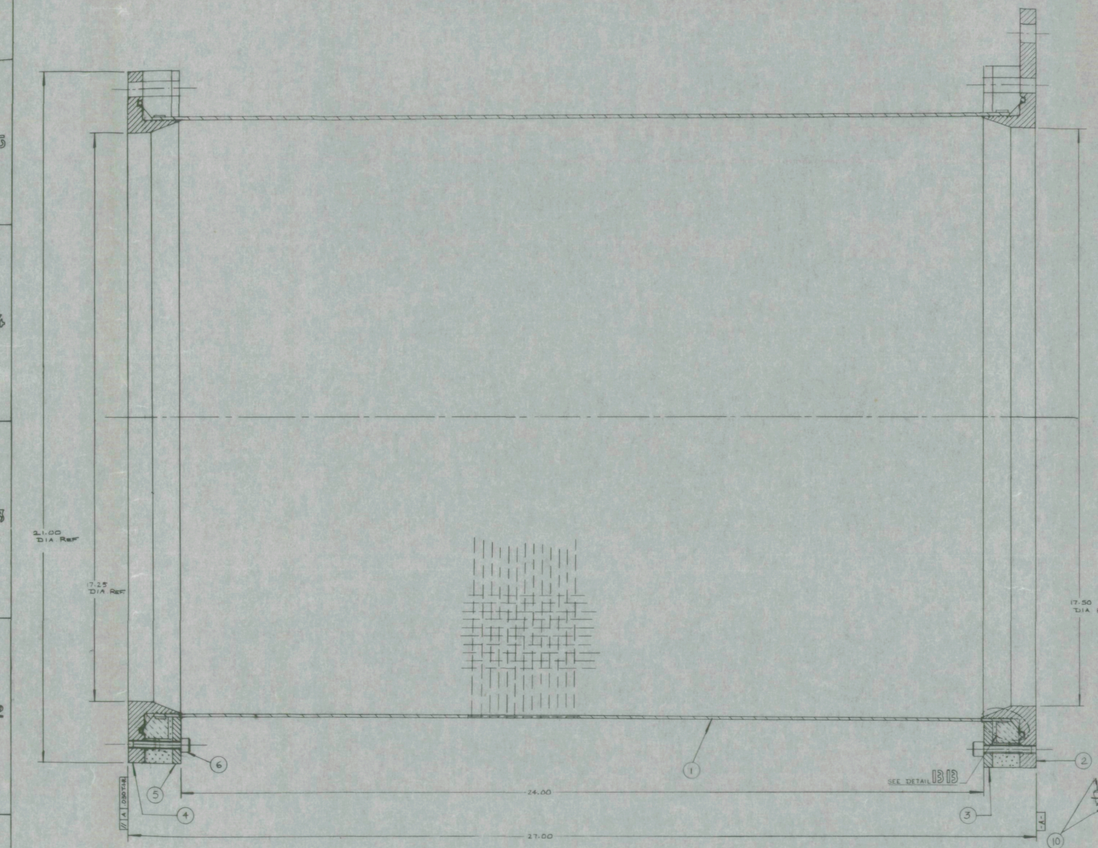
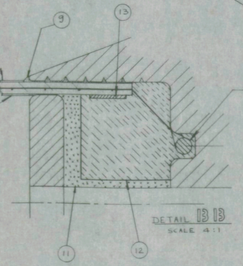


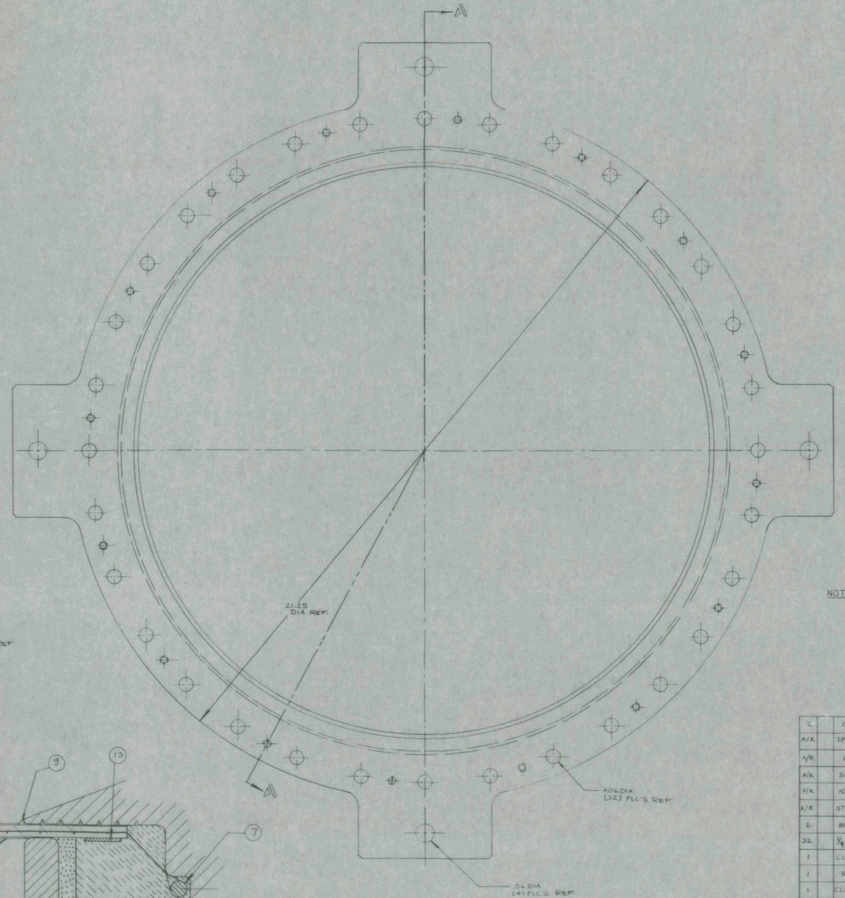

FIGURE 19 ATTACHMENT SYSTEM FOR PHASE II FLEXIBLE WINDOWS TO FITTINGS




SECTION A-A




DETAIL B
SCALE 4:1




NOTES:
1. ANGULAR ALLIGNMENT OF HOLES IN RINGS AT BOTH ENDS TO BE WITHIN 2°

| REV. LTR. | NOMENCLATURE OR DESCRIPTION | CODE IDENT | PART OR IDENTIFYING NO. | SPECIFICATION | MATERIAL | UNIT WT. | ITEM NO. |
|---|---|---|---|---|---|---|---|
| | LIST OF MATERIALS | | | | | | |
| C | CLAMP | | | | | | 13 |
| A/R | EPOXY RESIN | | | HARD EPOXY | | | 12 |
| A/R | URETHANE | | | CONAP | | | 11 |
| A/R | SILICONE FILM | | | DOW CORNING SYLGUARD 184 SILICONE | | | 10 |
| A/R | ADHESIVE | | | UNIVERSAL URETHANE ADHESIVE 4743-1 | | | 9 |
| A/R | STEEL WIRE | | | .143+.004 BRASS PLATED | | | 8 |
| 2 | BEAD RING | | FCD-54775 | | ALUM. | | 7 |
| 32 | 1/4-28 x 1/2 SOCKSEM | | | | STD. | | 6 |
| 1 | CLAMPING RING | | FCE-54772 | | ALUM. | | 5 |
| 1 | RING | | FCE-54771 | | ALUM. | | 4 |
| 1 | CLAMPING RING | | FCE-54774 | | ALUM. | | 3 |
| 1 | RING | | FCE-54773 | | ALUM. | | 2 |
| 1 | WIRE REINFORCED FLEX WINDOW CONSTRUCTION | | FCR-54769 | CONAP URETHANE & STEEL WIRE | | | 1 |

UNLESS OTHERWISE NOTED DIMENSIONS ARE IN INCHES
TOLERANCE ON:
FRACTIONS
DECIMALS XX± .XXX±
ANGLES
MATERIAL

LOCKHEED, Inc.
HUNTSVILLE, ALABAMA

FLEXIBLE OBSERVATION WINDOW
PHASE II

00333 R FCR-54770

NEXT ASSY | USED ON
APPLICATION

FIGURE 20. PHASE II FLEXIBLE WINDOW FITTINGS AND ATTACHMENT SYSTEM.

## PHASE II

## WINDOW TESTING

## PHASE II WINDOW TESTING

One flexible cylindrical window # US.L-4 of 45.72 cm diameter fabricated using brass plated wire reinforcement R-1 (see Table XVIII for netting pattern) was attached to fittings and then subjected to the following tests, utilizing appropriate test fixtures:

A. Pressure Testing Before Collapse/Extension Cycles

1. The window US.L-4 with closure plates (FCB-56776, Figure 24) was air pressurized to 24.30 nscm (35.0 psig) in successive steps of 3.47 nscm (5.0 psig). Pressure was held for 15.0 minutes at 24.30 nscm (35.0 psig) in order to verify the seal. No drop in pressure was observed.

2. After the successful verification of the seal, the window's closure plate (FCB-56776, Figure 24) was replaced by a window collapsing rod (FCD-56780, Figure 24), and then pressurized to 10.41 nscm (15.0 psig). The window was held under pressure for 24 hours and then checked for pressure loss. No drop in pressure was observed after 24 hours at 10.41 nscm. Pressure was released for transparency tests.

B. Verification of Transparency

For the verification of transparency, the "Human Factors Optical Test" developed in NASA Contracts NASI-5524 (Ref. 1) and NASI-7771 (Ref. 2) was conducted on window # US.L-4 and also on window # US.L-5 (containing black-coated wire reinforcement R-2). No pressure test was conducted on window # US.L-5. Optical tests, while viewing from inside out and outside in, were conducted and photographs were taken. Results are report in Table XIX. Figures 21 through 23 show the transparency of the flexible window when photographs were taken from outside at various distances.

TABLE XIX

HUMAN FACTORS OPTICAL TEST
FOR PHASE II WINDOW

| Eye Distance From Window (cm) | Human Factors | Window # US.L-4 | | | Window # US.L-5 | | | Remark |
|---|---|---|---|---|---|---|---|---|
| | | Before Pressure Testing | After Pressure Testing | After Pressure & 10 Cycles of Collapse/Extension Tests | Human Factors Optical Chart Distance from Window | Before Any Pressure Test | | |
| | | Viewing from Inside Out | | | | From Inside Viewing Out | From Outside Viewing In | |
| 25. | A | 2 | 2 | 2 | 25 | 1 | 1 | |
| | B | 2 | 1.5 | 2 | | 1 | 1.5 | |
| | C | 2 | 2 | 2 | | 1 | 1 | |
| | Last Leg. No. | 7860 | 7860 | 7860 | | 7860 | 7860 | |
| 50. | A | 3 | 3 | 3 | 50 | 1 | 1 | |
| | B | 2 | 2 | 3 | | 1.5 | 1.5 | |
| | C | 3 | 3 | 3 | | 1.5 | 1.5 | |
| | Last Leg. No. | 6379 | 6379 | 6379 | | 7860 | 7860 | |
| 100 | A | 3 | 3 | 3 | 100 | 2 | 2 | |
| | B | 3 | 3 | 3 | | 2.5 | 2 | |
| | C | 3 | 3 | 3 | | 2 | 2 | |
| | Last Leg. No. | 2439 | 2439 | 2439 | | 8307 | 8307 | |
| 200 | A | | | | 200 | 3 | 3 | Pattern obstructed the window clarity. Produced slightly cloudy vision in window #US.L-4. |
| | B | | | | | 3 | 3.5 | |
| | C | | | | | 3.5 | 3.5 | |
| | Last Leg. No. | | | | | 2439 | 2439 | |

NOTE: Human Factors Optical chart was placed 7 cm from the window wall when viewing inside the window from outside.

When viewing from inside the window, eyes were focused to obtain best results.

FIGURE 21

PHASE II - FLEXIBLE WINDOW
(45.7 cm diameter by 61.0 cm long)
WITH BLACK-COATED STEEL WIRE CABLE
REINFORCEMENT, R-2.

FIGURE 22

PHASE II - FLEXIBLE WINDOW
(45.7 cm diameter by 61.0 cm long)
WITH STEEL WIRE CABLE REINFORCEMENT, R-2.
Photograph taken at a distance of 100 cm
from the window wall.

FIGURE 23

PHASE II - FLEXIBLE WINDOW
(45.7 cm diameter by 61.0 cm long)
WITH BLACK-COATED STEEL WIRE
CABLE REINFORCEMENT, R-2.
Photograph taken at a distance of 200 cm
from the window wall.

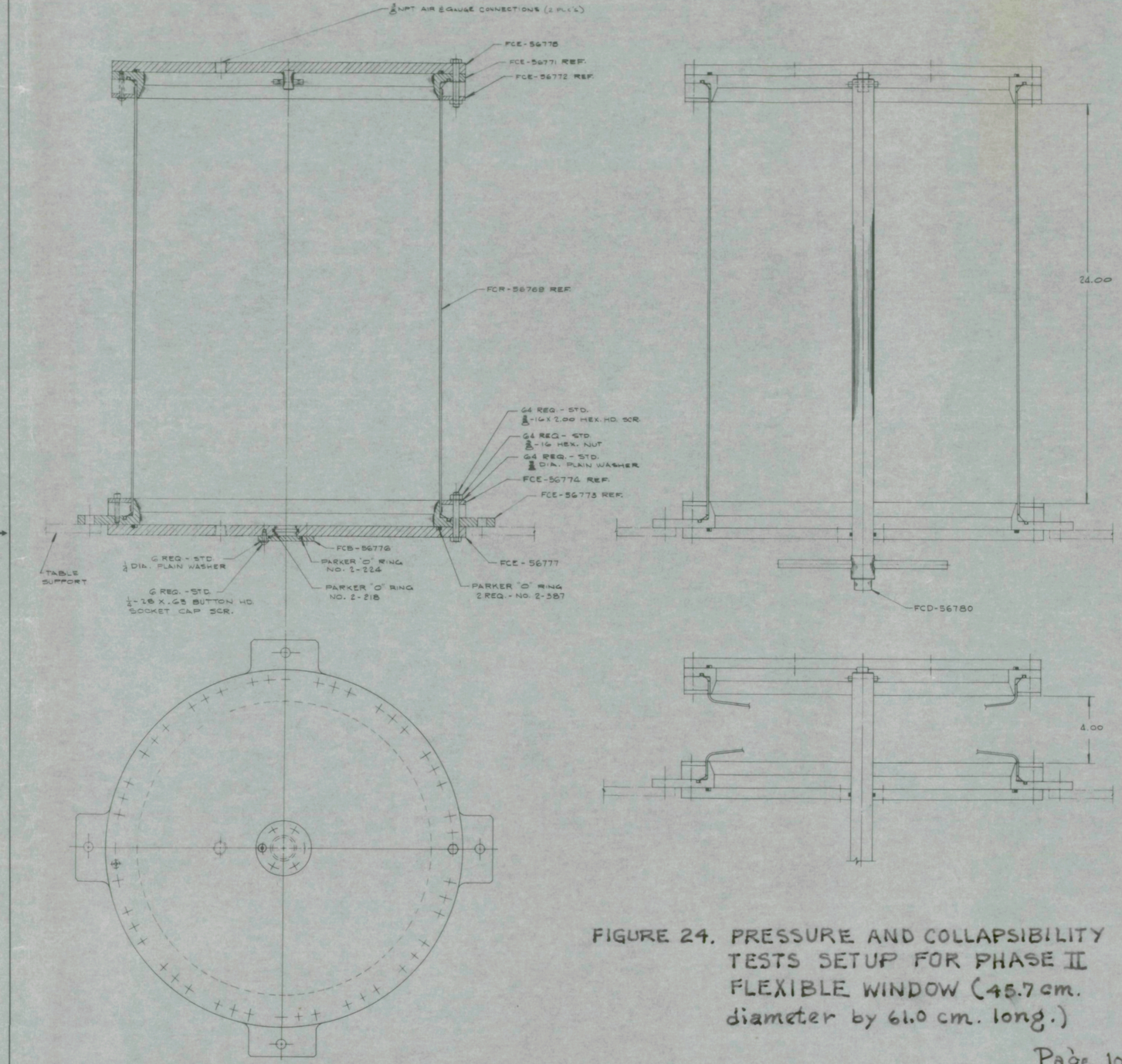
C. Collapsibility Test

For collapse/extension cycle tests, the bottom fitting of flexible window # US.L-4 was firmly secured in a fixture and then attempts were made to manually twist the upper portion of the window using the collapsing rod (FCD-56780, Figure 24) hinged to a notch in the top pressure plate. To allow for a twisting pantographic motion, as the cylindrical window is being collapsed upon itself through the application of mechanical force, it was found that the torque needed to collapse the window to at least one-sixth of its original length during the first cycle was much higher than anticipated. The main governing parameters for high torque were the airtight seal around the collapsing rod and the very large diameter of the pressure plate as compared to the collapsing-rod-hinge diameter. The use of lubricating oil on the collapsing rod reduced the friction considerably between the airtight Parker "O" ring seal and the collapsing rod surface.

After the successive collapse/extension cycles, the window could easily be collapsed from 61.0 cm its original length to 10.0 cm collapsed length and kept in its collapsed condition (under its own pressure plate weight) without an external locking device. Figures 25 through 32 show the window positions after various cycles of collapse/extension.

Human Factors Optical Test was conducted after ten cycles of collapsed/extension. Test results are shown in Table XIX. Visual examinations made after 24 hours pressure tests and ten cycles of collapse/extension are given in Table XX.

It was observed that there was a slight delamination of the silicone film, near the fittings, where the thickness of the silicone film (sylgard 184) was much higher than the main body of the window. The slight delamination in the silicone films from the urethane matrix did not interfere with window performance.




NOTE:
FOR ASSY. OF WINDOW SEE FCR-56770

FIGURE 24. PRESSURE AND COLLAPSIBILITY TESTS SETUP FOR PHASE II FLEXIBLE WINDOW (45.7 cm. diameter by 61.0 cm. long.)

| QTY. REQ'D | ITA | NOMENCLATURE OR DESCRIPTION | CODE IDENT. | PART OR IDENTIFYING NO. | SPECIFICATION | MATERIAL | UNIT WT. | ZONE | ITEM NO. |
|---|---|---|---|---|---|---|---|---|---|
| LIST OF MATERIALS | | | | | | | | | |

UNIROYAL, Inc.
ENGINEERING SYSTEMS DEPARTMENT
MISHAWAKA, INDIANA 46544

| | | |
|---|---|---|
| DRAWN | K. NASUMA | 2-3-70 |
| TRACED | | |
| DESIGNED | | |
| CHK'D | | |

PRESSURE & COLLAPSIBILITY TEST SETUP PHASE II WINDOW

| | |
|---|---|
| 00333 | FCE-56981 |
| NEXT ASSY | NASA LANGLEY |

SHEET 1 OF 1

FCE-56781

TABLE XX

VISUAL QUALITY EVALUATION PHASE II WINDOW

| Observation in Window Composite | After 24 Hrs. Under 10.41 nscm | After Cycles of Collapse/Extension | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 3 | 5 | 7 | 9 | 10 | After 24 hrs in Collapsed Cond. |
| Collapsed Length, cm | - | 15.3 | 14.0 | 12.7 | 11.4 | 10.0 | 10.0 | 10.0 |
| Original Length, cm | - | 61.0 | | | | | | 61.0 |
| Delamination | | | | | | | | |
| Silicone Layer | No | No | No | No | No | No | 1* | 3** |
| Urethane Layer | No | No | No | No | No | No | No | No |
| Cracks | No | No | No | No | No | No | No | No |
| Marks | No | No | No | No | No | No | No | No |
| Cloudiness | No | No | No | No | No | No | 1* | Highly stressed areas |
| Visibility | Satisfactory | Slightly hindered at the points of cloudiness and bulged areas. | | | | | | Hindered where delamination and cloudiness occurred. |

*Delamination of silicone film at one spot only near fitting.

**Delamination of silicone film at two spots near fitting and one spot 8 cm above bottom fitting.

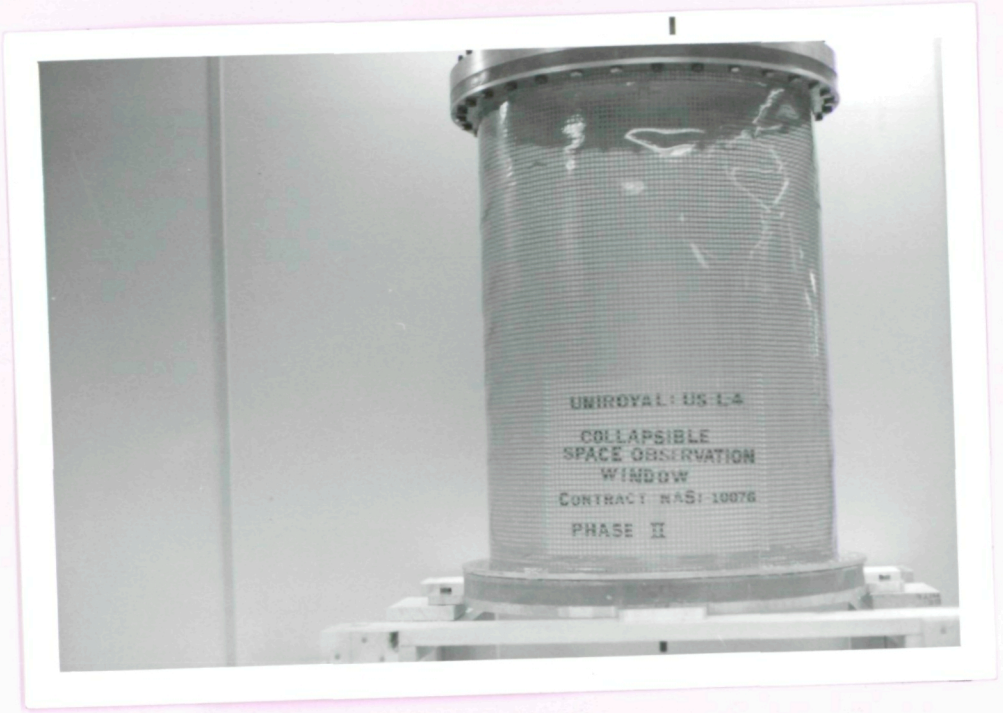



FIGURE 25

PHASE II - FLEXIBLE WINDOW # US.L-4
(45.7 cm diameter by 61.0 cm long)
BEFORE COLLAPSIBILITY TEST

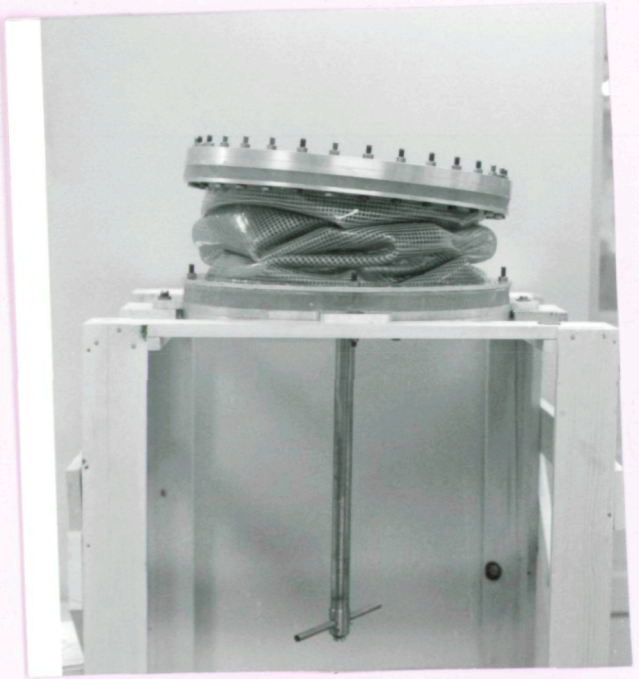


FIGURE 26

PHASE II - FLEXIBLE WINDOW # US.L-4
(45.7 cm diameter by 61.0 cm long)
COLLAPSED TO 15.3 cm IN THE FIRST CYCLE

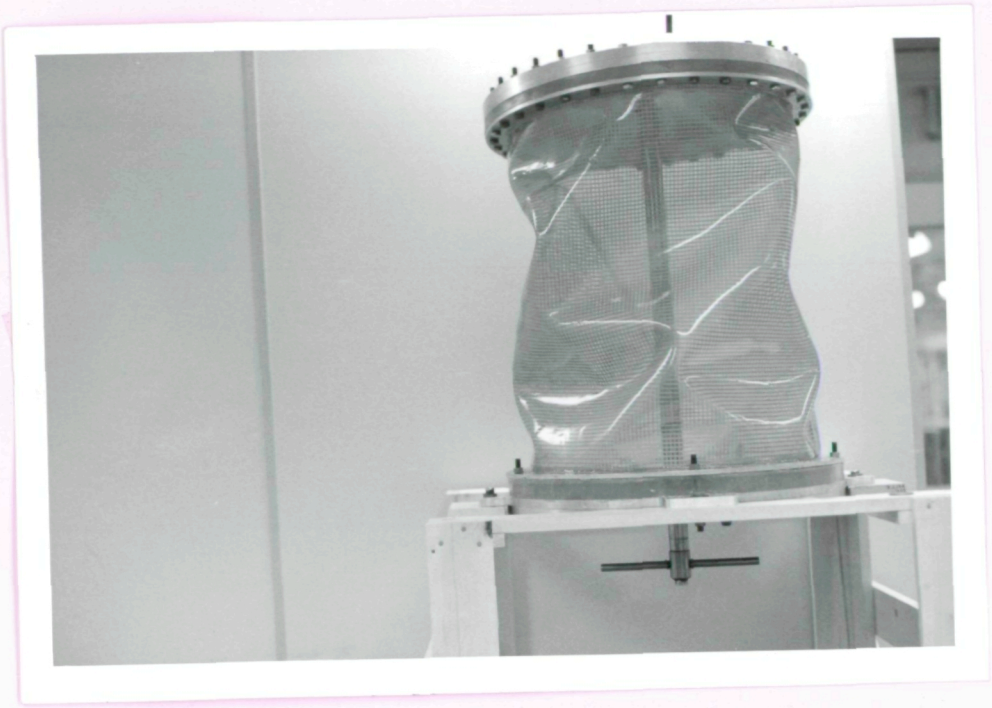


FIGURE 27

PHASE II - FLEXIBLE WINDOW # US.L-4
(45.7 cm diameter by 61.0 cm long)
AFTER 3 CYCLES OF COLLAPSE/EXTENSION

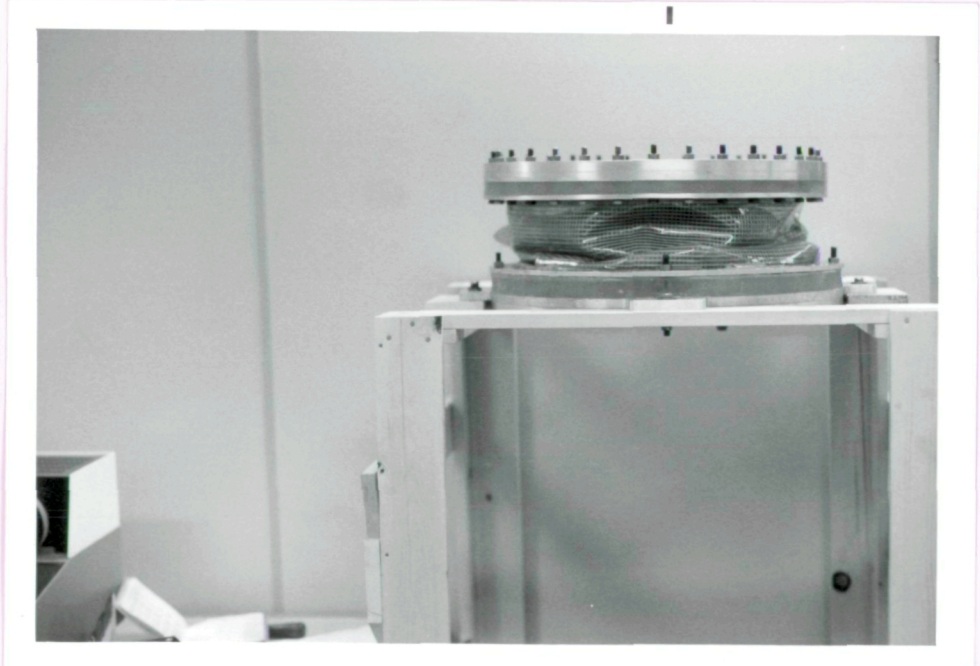


FIGURE 28

PHASE II - FLEXIBLE WINDOW # US.L-4
(45.7 cm diameter by 61.0 cm long)
COLLAPSED TO 11.4 cm AFTER SEVEN CYCLES OF
COLLAPSE/EXTENSION

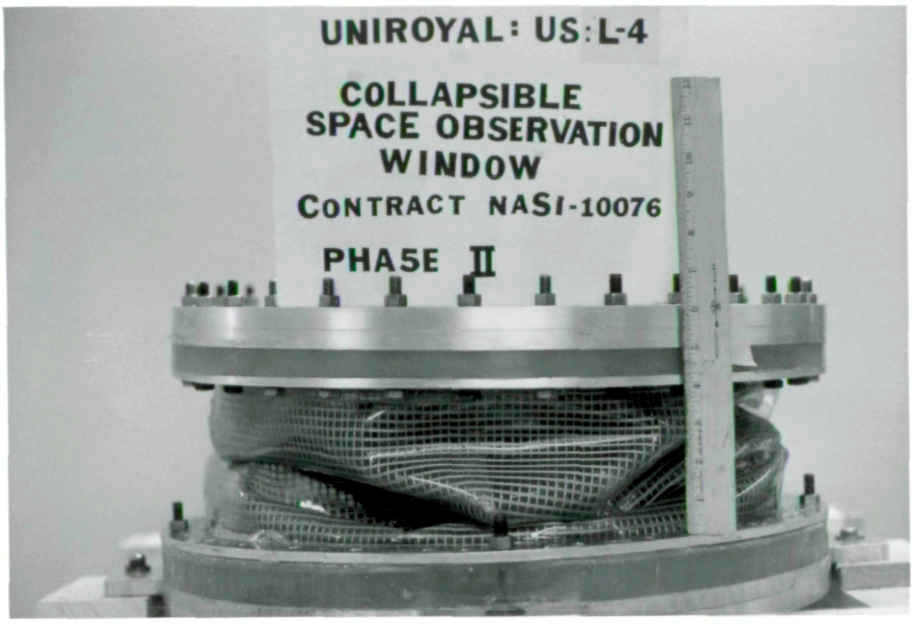



FIGURE 29

PHASE II - FLEXIBLE WINDOW #US.L-4
(45.7 cm diameter by 61.0 cm long)
COLLAPSED TO 10.0 cm AFTER TEN CYCLES OF
COLLAPSE/EXTENSION

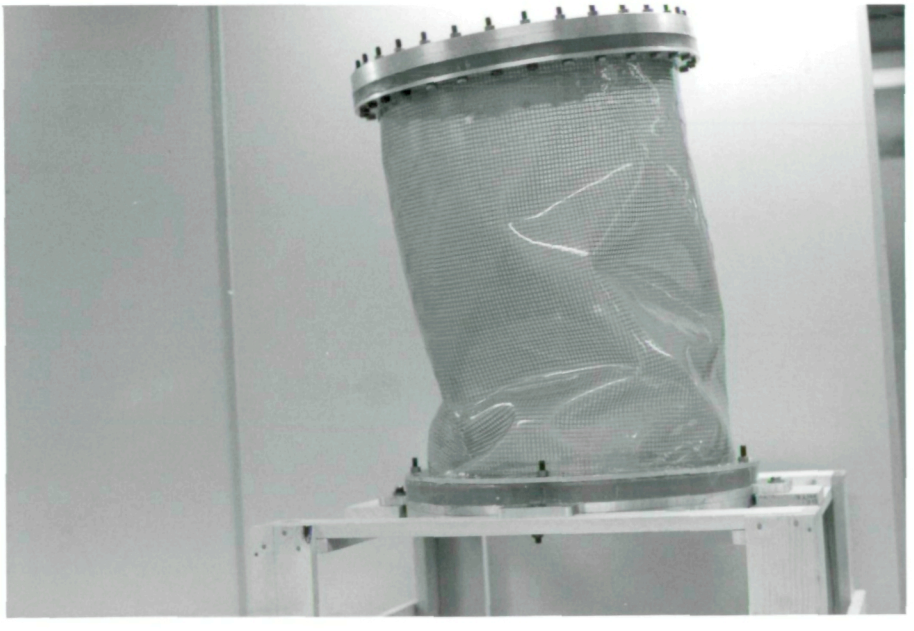


FIGURE 30

PHASE II - FLEXIBLE WINDOW #US.L-4
(45.7 cm diameter by 61.0 cm long)
EXTENSION AFTER TEN CYCLES OF COLLAPSE/EXTENSION

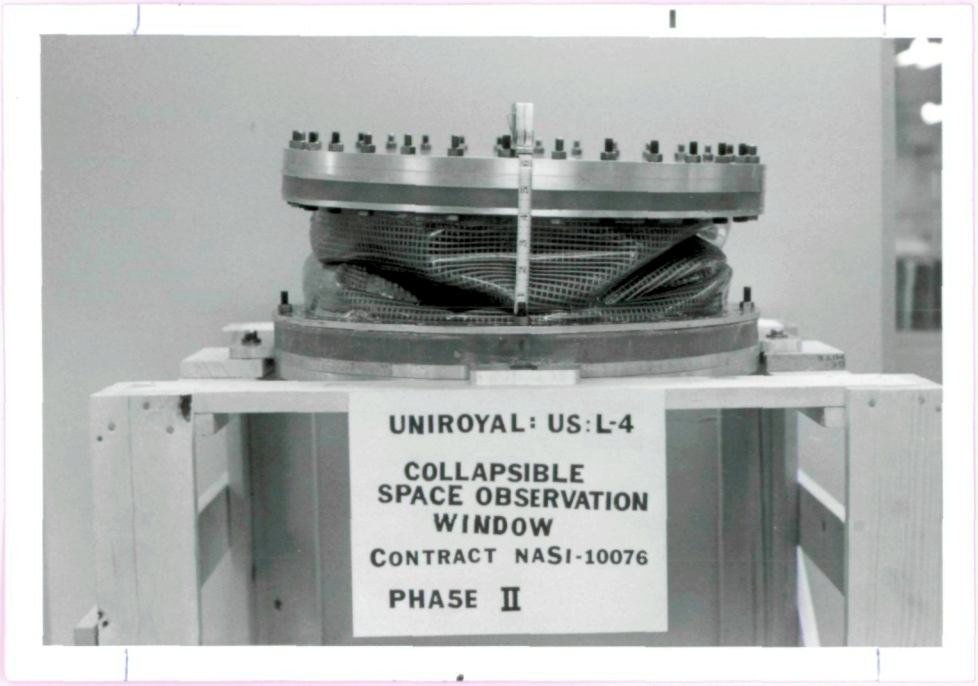



FIGURE 31

PHASE II - FLEXIBLE WINDOW #US.L-4
(45.7 cm diameter by 61.0 cm long)
COLLAPSED TO 10.0 cm UNDER ITS OWN WEIGHT
AFTER 10 CYCLES OF COLLAPSE/EXTENSION
AND 24 HOURS IN COLLAPSED CONDITION

FIGURE 32
PHASE II - FLEXIBLE WINDOW #US.L-4
(45.7 cm diameter by 61.0 cm long)
EXTENSION AFTER 10 CYCLES OF
COLLAPSE/EXTENSION and 24 HOURS IN
COLLAPSED CONDITION.
WINDOW NEEDED SUPPORT FOR EXTENSION.

D. Pressure Testing After 10 Cycles of Collapse/Extension and 24 hours in Collapsed Condition

1. Flexible window #US.L-4, having been subjected to 10 cycles of collapse/extension and 24 hours in collapsed condition (one-sixth of its original length), was again pressurized to 24.30 nscm (35.0 psig) and held for 15 minutes. No drop in pressure was observed, thus reflecting the retention of structural integrity of the window wall composite.
2. The same window #US.L-4 after high pressure testing, was held under an internal pressure of 10.41 nscm for 67 hours instead of 24 hours. The pressure gauge indicated a pressure drop of 0.33 nscm which was probably due to change in window environment condition or change in the window's physical condition under pressure. At the end of the test, visual examination of the window showed no bulging under 3.47 nscm pressure.

   Figure 33 shows the retention of structural integrity after pressure and collapsibility tests.

E. Blowout Strength

In order to determine the blowout strength of the window composite and fitting attachment system, the window #US.L-4 (having 24 ends/5 cm of axial reinforcement member and 40 ends/5 cm girth reinforcement member) was subjected to hydro burst pressure. For safety reasons, the window was filled with water except 4-5 cm of its length and then slowly air pressurized until it burst. The blowout strength was between 36.10-38.19 nscm (52.0-55.0 psig). It was interesting to note that failure did not occur in the preapplied urethane film seam. Visual examination revealed that failure first occurred in the girth reinforcement members near the fitting and then tear propagated throughout the length of the window. It is anticipated that uneven tension in the girth reinforcement

member might have been introduced while joining the wire ends at the completion of the girth winding.

No failure in the fitting attachment system was observed.

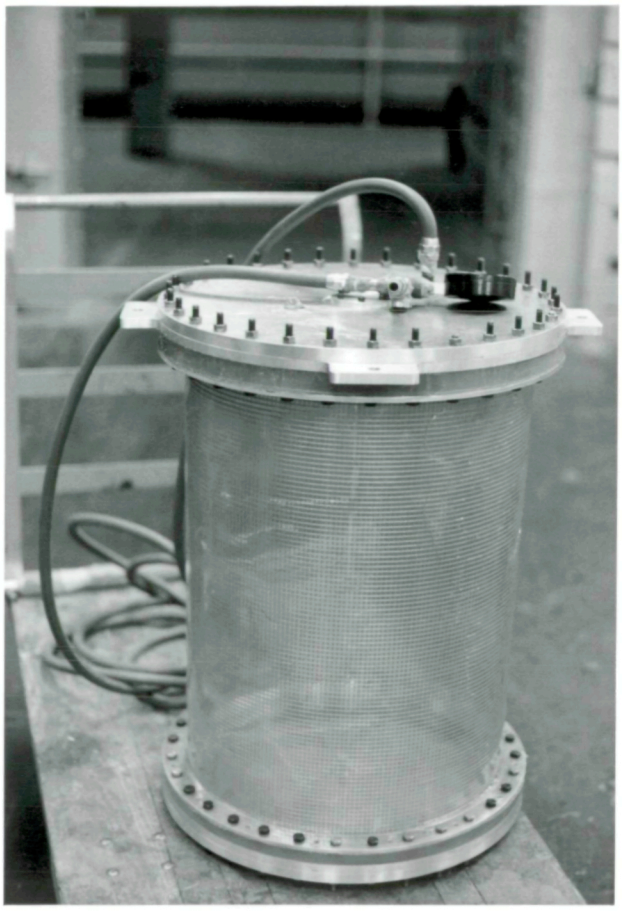


FIGURE 33

PHASE II - FLEXIBLE WINDOW #US.L-4
(45.7 cm diameter by 61.0 cm long)
PRESSURIZED TO 3.47 nscm AFTER 10 CYCLES
OF COLLAPSE/EXTENSION AND 24 HOURS IN
COLLAPSED CONDITION.
AIR PRESSURE EXTENDED THE WINDOW
WITHOUT ANY SUPPORT.

## CONCLUSIONS

Based upon the work conducted in the course of NASA Contract NASI-10076, the following conclusions may be drawn:

1. A transparent flexible cylindrical window capable of being utilized in space vehicles can be fabricated.
2. The most suitable method of reinforcement embedment for window fabrication is vacuum casting the composite's outer layer over the pre-applied urethane film and reinforcement wound on the male-section of the vac-mold. Due to the inherent bonding characteristics of the urethane material used, the fabrication of an optically transparent reinforced window composite is possible.
3. Satisfactory materials for use in fabricating the transparent, flexible window consist of black-coated carbon steel cable (as reinforcement) embedded in a matrix of a castable polyether urethane which in turn has a castable dimethyl RTV silicone laminated on both sides.
4. A dull black-coating of "Ebonol C" on the brass plated wire reinforcements (used in the window construction) reduces the reflection from the window reinforcement members and improves the apparent transparency of the window.
5. A cylindrical window of 45.7 cm diameter and 61.0 cm length, having reinforcement member at $0^{o}$ angle (axial reinforcements parallel to cylindrical axis), is capable of being collapsed to at least one-sixth of its original length by means of mechanical force.
6. The flexible transparent window with an overall composite wall thickness of 0.280 cm appears capable of withstanding the rigors of the outer space environment.

7. After 10 cycles of collapse/extension and 24 hours in collapsed condition (at least one-sixth of its original length), no major adverse effects were observed on the optical transparency and structural integrity of the cylindrical window.
8. Nonreinforced window laminae having dimethyl silicone (Sylgard 184) on both sides as a "barrier" had an upward flame propagation rate of 0.190 in./sec, an odor test score of maximum 1.2 with no dilution as compared to maximum allowed score of 2.5, carbon monoxide - 0.30 ugm/gm as compared to maximum allowed level of 100 ugm/gm; flash and fire points were in excess of 600° F tested temperature.
9. Cylindrical flexible window of 45.7 cm diameter when proof tested at 24.30 nscm and then held under 10.41 nscm pressure for 67 hours exhibited excellent pressure retention capability.
10. Transparent cylindrical window structure may be attached to circular fittings utilizing adhesive and mechanical means which in turn could easily be installed in a rigid walled space structure.

## RECOMMENDATIONS

During the course of the development work on the reinforced flexible transparent window, several areas considered worthy of future effort became apparent. The following areas are here advanced for consideration as extensions to the work initiated in Contract NASI-10076:

1. Evaluate other newly developed ultraviolet resistant transparent polymers for window application, such as Uralane XA-8666A/B*, which were unknown at the time of this study.
2. Apply the window fabrication technology developed during the course of this study, to the construction of flexible windows with double curvatures, such as domes, and develop other fabrication techniques for dome-type flexible window attached to only one set of fittings.
3. Evaluate flexible transparent cylindrical windows of larger than 45.7 cm diameter to reduce optical interference due to cylinder curvature and also provide for better photographic activities from inside the window.
4. Evaluate other flame retardant materials compatible with the window matrix polymers in order to improve the nonflammability of the window composite.
5. Evaluate suitable organic ultraviolet absorbers such as O-hydroxybenzophenones and 2-hydroxyphenyl benzotriazoles types with urethane polymer for added protection against the UV degradation of the window.

*A product of Furane Plastics, Inc., 5121 San Fernando Road West, Los Angeles, California 90039.

## LIST OF MATERIAL SUPPLIERS

| | Transparent Polymers | Supplier Address |
|---|---|---|
| 1. | Conathane EN-1554, Parts A & B (Polyether urethane) | Conap, Inc. 184 East Union St. Allegany, N. Y. 14706 |
| 2. | Sylgard 184 (Dow Corning RTV Silicone) | Magnuson Electronic, Inc. 5639 W. Fullerton Ave. Chicago, Ill. 60639 |
| | **Reinforcements** | |
| 3. | Brass Plated Carbon Rocket Wire Cable and Brass Plated Steel Wire | National Standard Co. Niles, Michigan |
| | **Adhesives** | |
| 4. | Conap AD-1146 (Urethane Adhesive) | Conap, Inc. 184 EAst Union St. Allegany, N. Y. 14706 |
| 5. | Chemlok 607 (Adhesive for Silicone Rubber and Specialty Elastomers) | Hughson Chemical Co. Div. of Lord Corp. 2000 W. Grandview Blvd. Erie, Pa. 16512 |
| | **Flame Retardants** | |
| 6. | Firemaster T23P Firemaster T33P | Michigan Chemical Co. 351 East Ohio St. Chicago, Ill. 60611 |
| 7. | Fyrol CEF Fyrol FR-2 | Stauffer Chemical Co. Specialty Chemical Div. 10 South Riverside Plaza Chicago, Ill. 60606 |
| 8. | Arocolor 1232 | Monsanto Company 800 N. Lindbergh Blvd. St. Louis, Mo. 63166 |
| | **Release Agents** | |
| 9. | RAM-225 (Mold Release Agent) | Ram Chemicals 210 E. Alondra Blvd. Gardena, Calif. 90247 |

| Release Agents (Cont'd.) | Supplier Address |
|---|---|
| 10. MS-122<br>(Fluorocarbon Dry Release Agent) | Miller-Stephenson Chem. Co.,Inc<br>1350 W. Fullerton Ave.<br>Chicago, Ill. 60614 |
| 11. DC-55<br>(Dow Corning Pneumatic Grease) | Dow Corning Corp.<br>Midland, Mich. 48640 |
| 12. Johnson's Paste Wax<br>(Wax Release Agent) | S. C. Johnson and Sons, Inc.<br>Racine, Wisconsin |
| **Epoxy Resins** | |
| 13. ERL-2256/ZZLB 0820 | Union Carbide Co.<br>Plastic Div.<br>270 Park AVe.<br>New York, N. Y. 10017 |
| 14. Epon 828<br>(Shell Epoxy Resin) | Shell Chemical Co.<br>A Division of Shell Oil Co.<br>New York, N. Y. |
| 15. DEH-14<br>(Dow Epoxy Hardener) | The Dow Chemical Co.<br>6000 W. Touhy Ave.<br>Chicago, Ill. 60648 |
| **Polyester** | |
| 16. Vibrathane 6001<br>(Moisture-Cure Liquid Polyester) | UNIROYAL Chemical<br>Division of UNIROYAL, Inc.<br>Naugatuck, Conn. 06770 |

## REFERENCES


1. Kohrn, Robert C., Kelsheimer, George E., Uhlig, Edwin C., and LaBelle, Becky S: Feasibility Study for Development of a Flexible Reinforced Window. NASA CR-66299, January, 1967.

2. Hile, Don E.,Jr.: Experimental and Theoretical Study for Development of an Improved Reinforced Flexible Window. NASA CR-66832, October, 1969.

3. Procedures and Requirements for the Flammability and Outgassing Evaluation of Manned Spacecraft Non-metallic Materials. NASA MSC-D-NA-0002, July, 1968.

4. Whipple, Clyde E. and Thorne, John A.: Performance of Elastomeric Silicone in Ablative and Space Environments. Dow Corning Aerospace Applications Laboratories Report No. 196 - Paper Presented at American Chemical Society (Division of Rubber Chemistry), May, 1966.

5. Juvinall, Robert C.: Engineering Considerations of Stress, Strain, and Strength. McGraw-Hill Series in Mechanical Engineering, 1967.

6. Physical Properties of Common Organic Solvents Chart. Hoosier Solvents and Chemicals Corp., 1968.

7. Pasto, Daniel J., Johnson, Carl R.: Organic Structure Determination. Prentice-Hall, Inc. Publication, page 85, 1969.

# APPENDIX A

# TEST METHODS

## TEST METHODS — APPENDIX A

1. Heat Aging Test

Electrically heated hot air circulating oven was used for sample aging. Test samples 6 x 6 (15.25 cm x 15.25 cm) were suspended in the oven and aged for one week at 212°F (100°C).

2. Ultraviolet Radiation Aging Test

Test specimens 3" x 5-1/2" were subjected to "UV" exposure for 240 hours (10 days) in an Atlas Fadeometer, Model 18-F. Test was performed in accordance with ASTM procedure D-750-55T. Test samples were placed in a fixture, in an unstrained condition, and exposed to the effect of light having essentially the same wavelengths as found in nature sunlight but with increased intensity in the ultraviolet range. Temperature, within the exposure unit utilized, was maintained at 155 ± 4°F (68° ± 2°C). Based upon the estimated calculations, agings for 240 hours in Fadeometer are equivalent to the ultraviolet exposure experienced during 29 days in orbit.

3. Light Transmittance

The percent light transmittance through the polymer films with and without flame retardant was determined over the full range of the visible spectrum (380 mu - 700 mu) using a General Electric "Recording Spectrophotometer". The "Recording Spectrophotometer" consists of essentially three (3) units - the monochrometer, a photometer, and a recorder. The monochrometer breaks up the white light into the spectrum colors, each at a band width of 10 millimicrons. The photometer system illuminates the sample either (by transmittance or reflectance) with monochromatic light and furnishes a measurement signal of this light to the recorder, and in return, recorder provides a curve exhibiting complete specification.

3. Light Transmittance (continued)

The instrument can be used to measure color in the visible or near ultraviolet *(also known as quartz ultraviolet region (Ref. 7) extending from 200 - 350 mu)region of spectrum.

The respective wavelength bands selected for tabulation in Data Tables XXI and XXII, Appendix B, cover the following continuous spectrum:

| Wavelength Range ** (mu) | Color |
|---|---|
| 400 - 424 | Violet |
| 425 - 490 | Blue |
| 491 - 575 | Green |
| 576 - 585 | Yellow |
| 586 - 647 | Orange |
| 648 - 700 | Red |

* The "Vacuum" or far ultraviolet region extends from 100 mu to approximately 200 mu.

** Maximum visibility in daylight or brilliant artificial light is 556 mu.

## 4. DeMattia Flex Test

The test equipment essentially consists of two clamping jaws 14" in length mounted on a fixture. The top jaw is adjustable while the bottom jaw is connected to an eccentric wheel causing vertical to and fro motion in the jaw.

Specimens of 1" x 8" strips were cut from lamina having two layers of urethane films bonded together. Cut strips can be twisted and mounted in between the jaws separated by a designated distance. A counter records the number of flex cycles. After required number of flex cycles, samples are visually examined for cracks or delamination.

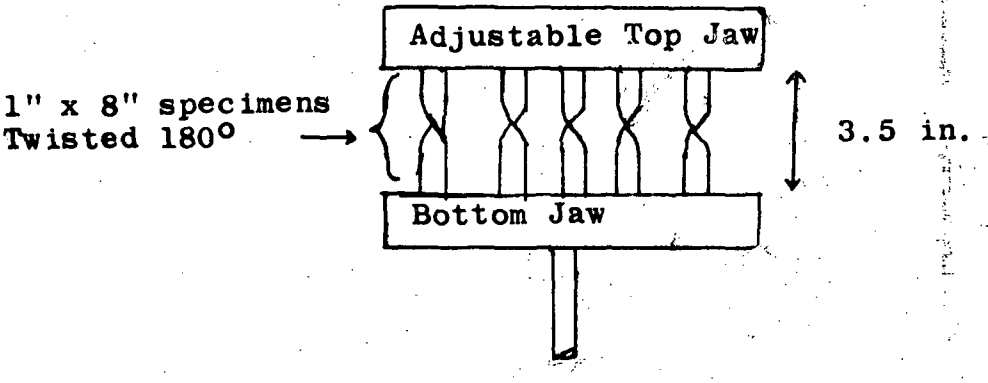



Figure 34. DeMattia Flex Test Machine. Manufactured by DeMattia, Inc., U.S.A. for Shoe-Sole Testing.

5. Tensile Strength and Elongation Test

Reinforcement member tensile strength and elongation was obtained by utilizing an Instron Test Machine operating at a jaw speed of 2.54 cm per minute. Specimen length of 25.4 cm was tested using "D" type cell and the chart speed was 12.70 cm/minute. Percent elongation was read from the stress-strain chart.

6. NASA-WSTF Laboratory Tests

Test Procedures: Selected films and non-reinforced laminae were supplied to NASA-WSTF Laboratory for comprehensive evaluation in accordance with Category A requirements described in Reference 3. A complete description of the test procedure is contained in Reference 3 while a brief description of each test performed is included here for convenience.

The tests performed were as follows:

(1) Upward Flame Propagation Rate - Test No. 1

A 2-1/2 x 5 inch sample is mounted in a vertical position in a 100 percent oxygen 6.2 psia environment. An attempt is then made to ignite the sample using a silicone rubber ignitor.

Materials are considered acceptable for Category A if they:

(a) Do not ignite.

(b) Ignite but self-extinguish after burning 0.5 inch or less after extinguishment of the igniter and do not spark, sputter, or drip flaming particles.

6. NASA-WSTF Laboratory Tests (continued)

(2) Flash and Fire Point - Test No. 3

The material is installed in a special test appartus containing an atmosphere of 100 percent oxygen at 6.2 psia. The sample is then heated at a constant rate of 25°F/min. and examined for ignition at the end of each 25°F rise by applying an electrical spark. To be acceptable, materials:

(a) Must not evolve vapors which produce a visible flash at a temperature less than 400°F.

(b) Must not show evidence of charring or self sustained combustion at a temperature less than 450°F.

(3) Carbon Monoxide and Offgassing Products - Test No. 6

A sample is placed in a sealed container containing 100 percent oxygen atmosphere and then heated to 155 ± 5°F for 72 hours. The atmosphere within the container is then examined to determine the carbon monoxide level and total organic offgassing products level. Materials are considered acceptable if they produce levels that do not exceed 100 micrograms of total organics per gram of sample and 25 micrograms of carbon monoxide per gram of sample.

(4) Odor Test - Test No. 7

Materials are heated in a test chamber at 155°F temperature for 72 hours in an oxygen atmosphere. Following the oven treatment, known volumes of the atmosphere from the container are removed and diluted with fresh oxygen in the following proportions:

(4.) Odor Test - Test No. 7 (continued)

(a) One part sample atmosphere to 29 parts of test gas.

(b) One part sample atmosphere to 9 parts of test gas.

(c) No dilution (Same as drawn from the container).

The prepared test samples are supplied to a ten member panel for evaluation. Each panel member evaluates the odor of a sample according to the following scale:

| Member Rating | Test Conductor's Rating |
|---|---|
| Undetectable | 0 |
| Barely Detectable | 1 |
| Easily Detectable | 2 |
| Objectionable | 3 |
| Irritating | 4 |

Materials are considered acceptable if a ten member panel average is 2.5 or lower. An average score above 2.5 at any dilution signifies that the material failed.

(5.) DTA and TGA Analysis - Special Test

Differential thermal analysis (DTA) and thermogravimetric analysis (TGA) tests were conducted on the materials in 100 percent oxygen atmosphere at a pressure of 320 Torr. DTA tests involve the continuous comparison of temperatures of a reference material as a sample as they are both heated at a uniform rate. From the direction of deviation in temperature between the sample and reference, exothermic or endothermic transformation is established. TGA measures the weight of the sample as it is heated at a uniform rate. Examination of both DTA and TGA curves for a particular sample show whether a loss of weight accompanies an endothermic or exothermic change, i.e. TGA greatly assists in the interpretation of the DTA results and thus provides information on the stability of a material.

# APPENDIX B

# TEST DATA TABLES

DATA TABLE XXI APPENDIX B

PHASE I - FLAME RETARDANT EVALUATION IN URETHANE FILMS HEAT AGED 1 WEEK AT 212°F

PERCENT LIGHT TRANSMITTANCE*

| Code No. | F.R(%) | Aging Cond.** | Thickness mm | % Light Transmittance at Wavelength 400 mu | 420 mu | 490 mu | 575 mu | 585 mu | 642 mu | 700 mu |
|---|---|---|---|---|---|---|---|---|---|---|
| 3F15 | 15% T33P | Unaged | 2.387 | 15.5 | 26.0 | 64.5 | 85.5 | 86.0 | 87.0 | 87.5 |
| 3F15(A) | 15% T33P | Aged 1 Wk. @ 212°F | 2.362 | 2.0 | 2.5 | 24.5 | 48.5 | 53.5 | 70.0 | 78.0 |
| 3F0 | 0 | Unaged | 2.692 | 10.5 | 21.0 | 61.5 | 84.0 | 84.5 | 85.0 | 87.0 |
| 3F0(A) | 0 | Aged 1 Wk. @ 212°F | 2.286 | 2.5 | 6.0 | 34.0 | 59.5 | 63.0 | 76.0 | 81.5 |
| 4F15 | 15% Fyrol CEF | Unaged | 2.464 | 16 | 25.5 | 63.5 | 85.0 | 85.5 | 86.5 | 87.5 |
| 4F15(A) | 15% Fyrol CEF | Aged 1 Wk. @ 212°F | 2.311 | 2.5 | 2.5 | 14.5 | 38.5 | 42.5 | 62.0 | 72.5 |
| 4F0 | 0 | Unaged | 2.438 | 11.0 | 22.5 | 63.5 | 84.5 | 85.0 | 86.0 | 87.5 |
| 4F0(A) | 0 | Aged 1 Wk. @ 212°F | 2.438 | 2.5 | 6.5 | 36.0 | 60.5 | 63.5 | 76.5 | 81.5 |
| 5F15 | 15% Aroclor 1232 | Unaged | 2.184 | 20.5 | 33.0 | 68.5 | 80.0 | 80.5 | 82.0 | 83.0 |
| 5F15(A) | 15% Aroclor 1232 | Aged 1 Wk. @ 212°F | 2.235 | 7.0 | 6.5 | 18.0 | 50.5 | 53.5 | 66.0 | 73.0 |
| 5F0 | 0 | Unaged | 2.489 | 19.0 | 30.0 | 62.5 | 74.5 | 75.5 | 77.5 | 79.5 |
| 5F0(A) | 0 | Aged 1 Wk. @ 212°F | 2.540 | 6.0 | 6.0 | 18.0 | 47.0 | 49.5 | 62.5 | 70.0 |

* For test method see Appendix A

** See Appendix C for percent light transmittance curves

DATA TABLE XXII APPENDIX B

PHASE I - FLAME RETARDANT EVALUATION IN URETHANE FILMS AGED FOR 240 HOURS - ULTRAVIOLET

PERCENT LIGHT TRANSMITTANCE*

| Code No. | F.R. (%) | ** Condition | Thickness mm | % Light Transmittance at Wavelength 400 mu | 420 mu | 490 mu | 575 mu | 585 mu | 642 mu | 700 mu |
|---|---|---|---|---|---|---|---|---|---|---|
| 3F15 | 15% T33P | Unaged | 2.337 | 17.5 | 27.0 | 65.0 | 85.5 | 86.0 | 87.0 | 87.5 |
| 3F15 (U.V.) | 15% T33P | Aged 240 Hrs. Ultraviolet | 2.311 | 2.0 | 2.0 | 10.5 | 52.0 | 55.0 | 70.0 | 79.5 |
| 3F0 | 0 | Unaged | 2.616 | 10.0 | 21.5 | 62.5 | 84.0 | 84.5 | 86.0 | 87.0 |
| 3F0 (U.V.) | 0 | Aged 240 Hrs. Ultraviolet | 2.565 | 2.0 | 2.5 | 11.5 | 52.5 | 56.0 | 69.5 | 76.5 |
| 4F15 | 15% Fyrol CEF | Unaged | 2.489 | 14.0 | 24.5 | 63.0 | 65.0 | 85.5 | 86.5 | 87.5 |
| 4F15 (U.V.) | 15% Fyrol CEF | Aged 240 Hrs. Ultraviolet | 2.337 | 2.5 | 2.5 | 14.0 | 55.0 | 58.5 | 71.5 | 78.0 |
| 4F0 | 0 | Unaged | 2.515 | 10.5 | 21.5 | 63.0 | 65.0 | 85.5 | 86.5 | 87.5 |
| 4F0 (U.V.) | 0 | Aged 240 Hrs. Ultraviolet | 2.489 | 2.5 | 2.5 | 14.5 | 54.5 | 58.0 | 70.0 | 76.5 |
| 5F15 | 15% Aroclor 1282 | Unaged | 2.261 | 43.0 | 60.5 | 73.5 | 78.5 | 79.0 | 80.5 | 82.0 |
| 5F15 (U.V.) | 15% Aroclor 1232 | Aged 240 Hrs. Ultraviolet | 2.159 | 0.5 | 2.5 | 22.0 | 50.0 | 52.5 | 64.5 | 71.5 |
| 5F0 | 0 | Unaged | 2.438 | 38.0 | 52.5 | 68.5 | 74.0 | 74.5 | 77.0 | 78.0 |
| 5F0 (U.V.) | 0 | Aged 240 Hrs. Ultraviolet | 2.413 | 0.0 | 1.5 | 20.0 | 50.0 | 52.5 | 63.5 | 70.0 |

* For test method see Appendix A

** See Appendix C for transmittance curves.

## TABLE XXIII

### STRENGTH TEST DATA ON REINFORCEMENT MATERIALS USED

| R-1 BRASS PLATED WIRE CABLE (9 STRANDS) | | R-2 CARBON ROCKET WIRE CORD OF 7 STRANDS - BLACK COATING | |
|---|---|---|---|
| Ultimate Brk. Strength/End (Kg) | % Elongation | Ultimate Brk. Strength/End (Kg) | % Elongation |
| 13.38 | 2.00 | 13.47 | 1.40 |
| 13.47 | 2.00 | 14.29 | 1.60 |
| 13.47 | 1.90 | 13.93 | 1.50 |
| 13.43 | 2.00 | 14.15 | 1.60 |
| 13.47 | 2.00 | 13.47 | 1.50 |
| 13.38 | 1.90 | 14.52 | 1.80 |
| 13.47 | 1.90 | 13.97 | 1.50 |
| 13.38 | 2.00 | 14.38 | 1.70 |
| 13.43 | 2.00 | 13.93 | 1.50 |
| 13.38 | 1.90 | - | - |
| 13.38 | 2.00 | - | - |
| 13.38 | 2.00 | - | - |
| AVE. 13.42 | 1.97 | 14.01 | 1.57 |
| RANGE 0.09 | 0.10 | 1.05 | 0.40 |
| MIN. 13.38 | 1.90 | 13.47 | 1.40 |

DATA TABLE XXIV-A APPENDIX B

CONATHANE EN-1554 FILM WITH 10% FYROL FR-2

(1:C-F)

COMBUSTION RATE TEST (Upward)

| | TEST NUMBER 1 | 2 | 3 | AVERAGE |
|---|---|---|---|---|
| Test Atmosphere | Oxygen | Oxygen | Oxygen | Oxygen |
| Test Pressure (psia) | 6.2 | 6.2 | 6.2 | 6.2 |
| Sample Size (inches) | 5x2.5x.045 | 5x2.5x.045 | 5x2.5x.045 | 5x2.5x.045 |
| Comb. Rate (in/sec) | 0.368 | 0.379 | 0.410 | 0.386 |

OBSERVATIONS/COMMENTS: The material burned with yellow-orange flames and emitted moderate amounts of smoke and soot, and large numbers of sparks and falling burning particles. The residue was black soot and ash.

DATA TABLE XXIV-B

CONATHANE EN-1554 FILM

(2:C)

COMBUSTION RATE TEST (Upward)

| | TEST NUMBER 1 | 2 | 3 | AVERAGE |
|---|---|---|---|---|
| Test Atmosphere | Oxygen | Oxygen | Oxygen | Oxygen |
| Test Pressure (psia) | 6.2 | 6.2 | 6.2 | 6.2 |
| Sample Size (inches) | 5x2.5x.020 | 5x2.5x.020 | 5x2.5x.020 | 5x2.5x.020 |
| Comb. Rate (in/sec) | 0.345 | 0.417 | 0.385 | 0.382 |

OBSERVATIONS/COMMENTS: The material burned with yellow-orange and blue flames and emitted moderate amounts of smoke and soot, and large numbers of sparks and falling burning particles. The residue was a small amount of gummy black and brown substance and black ash.

## DATA TABLE XXIV-C

SYLGARD 184 - SILICONE FILM

(3:S)

| FLAME PROPAGATION RATE (Upward) | SAMPLE NUMBER 1 | 2 | 3 | TEST CHAMBER SZ 4 ft$^3$ AVG. |
|---|---|---|---|---|
| Sample Geometry L"XW"XH" | 5x2.5x.040 | 5x2.5x.040 | 5x2.5x.040 | 5x2.5x.040 |
| Test Atmosphere | Oxygen 6.2 | Oxygen 6.2 | Oxygen 6.2 | Oxygen 6.2 |
| Flame Propagation Rate | 0.233 | 0.287 | 0.291 | 0.270 |

Observations: The material burned with intense blue, orange and yellow flames and emitted moderate amounts of smoke, large amounts of fluff and soot, and large numbers of sparks and falling burning particles. The residue was gray-black friable ash. The average final chamber pressure was 7.3 psia.

## DATA TABLE XXIV-D

LAMINA: SYLGARD 184/CONATHANE EN-1554 WITH 10% FYROL FR-2/SYLGARD 184

(4:S/C-F/S)

| FLAME PROPAGATION RATE (Upward) | SAMPLE NUMBER 1 | 2 | 3 | TEST CHAMBER SZ 4 ft$^3$ (AV |
|---|---|---|---|---|
| Sample Geometry L"XW"XH" | 5x2.5x.090 | Same | Same | 5x2.5x0.090 |
| Test Atmosphere (6.2 psia) | Oxygen | Same | Same | Oxygen |
| Flame Propagation Rate (ips) | 0.167 | 0.153 | 0.159 | 0.160 |

Observations: The material burned with intense yellow-orange flames and emitted large amounts of smoke and soot, and large numbers of falling burning particles. The residue was a gray-black friable ash. The average final chamber pressure was 9.6 psia.

## DATA TABLE XXIV-E

LAMINA: SYLGARD 184/CONATHANE EN-1554/SYLGARD 184

(5;S/C/S)

| FLAME PROPAGATION RATE (Upward) Chamber 4 ft$^3$ | SAMPLE NUMBER 1 | 2 | 3 | TEST CHAMBER SZ 4 ft$^3$ |
|---|---|---|---|---|
| Sample Geometry L"XW"XH" | 5x2.5x.090 | Same | Same | 5x2.5x0.090 |
| Test Atmosphere(6.2 psia) | Oxygen | Same | Same | Oxygen |
| Flame Propagation Rate(ips) | 0.210 | 0.179 | 0.180 | 0.190 |

Observations: The material burned with intense yellow-orange flames and emitted large amounts of smoke, moderate numbers of sparks with large numbers of falling burning particles, and large amounts of soot. The residue was gray-black friable ash. The average final chamber pressure was 10.2 psia.

## DATA TABLE XXV-A APPENDIX B

CONATHANE EN-1554 FILM WITH 10% FYROL FR-2

(1:C-F)

WSTF# 71-2450
MSC# 2965

FLASH AND FIRE POINT TEMPERATURE TEST

| | TEST NUMBER | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | AVERAGE |
| Test Atmosphere | Oxygen | Oxygen | Oxygen | Oxygen |
| Test Pressure (psia) | 6.2 | 6.2 | 6.2 | 6.2 |
| Sample Weight (gms) | 0.500 | 0.495 | 0.502 | 0.499 |
| Flash Point (°F) | None | None | None | SEE COMMENTS |
| Fire Point (°F) | None | None | None | SEE COMMENTS |

OBSERVATIONS/COMMENTS: The material melted, discolored from clear to black, and emitted moderate amounts of smoke and small amounts of soot. Tested to 600°F (315°C)

## DATA TABLE XXV-B

CONATHANE EN-1554 FILM

(2:C)

WSTF# 71-2451
MSC # 2966

FLASH AND FIRE POINT TEMPERATURE TEST

| | TEST NUMBER | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | AVERAGE |
| Test Atmosphere | Oxygen | Oxygen | Oxygen | Oxygen |
| Test Pressure (psia) | 6.2 | 6.2 | 6.2 | 6.2 |
| Sample Weight (gms) | 0.505 | 0.504 | 0.503 | 0.504 |
| Flash Point (°F) | None | None | None | SEE COMMENTS |
| Fire Point (°F) | None | None | None | SEE COMMENTS |

OBSERVATIONS/COMMENTS: The samples melted, discolored from clear to amber, and emitted small amounts of smoke and soot. No flash or fire points were observed to 600°F (315°C).

## DATA TABLE XXV-C

SYLGARD 184 - SILICONE FILM
(3:S)

WSTF # 71-2449
MSC # 2964

FLASH AND FIRE POINT TEMPERATURE TEST

| | TEST NUMBER | | | AVERAGE |
|---|---|---|---|---|
| | 1 | 2 | 3 | |
| Test Atmosphere | Oxygen | Same | Same | Oxygen |
| Test Pressure (psia) | 6.2 | Same | Same | 6.2 |
| Sample Weight (gms) | 0.502 | 0.496 | 0.496 | 0.498 |
| Flash Point ($^{o}$F)/($^{o}$C) | None | None | None | None |
| Fire Point ($^{o}$F)/($^{o}$C) | None | None | None | None |
| OBSERVATIONS/COMMENTS: | No flash or fire points were observed to 600$^{o}$F (315$^{o}$C) and no sample changes were noted. | | | |

## DATA TABLE XXV-D

LAMINA: SYLGARD 184/CONATHANE EN-1554 WITH 10% FYROL FR-2/SYLGARD 184
(4:S/C-F/S)

WSTF # 71-2448
MSC # 2963

FLASH AND FIRE POINT TEMPERATURE TEST

| | TEST NUMBER | | | AVERAGE |
|---|---|---|---|---|
| | 1 | 2 | 3 | |
| Test Temperature | Oxygen | Same | Same | Oxygen |
| Test Pressure (psia) | 6.2 | Same | Same | 6.2 |
| Sample Weight (gms) | 0.505 | 0.503 | 0.499 | 0.502 |
| Flash Point ($^{o}$F)/($^{o}$C) | None | None | None | None |
| Fire Point ($^{o}$F)/($^{o}$C) | None | None | None | None |
| OBSERVATIONS/COMMENTS: | The samples melted, discolored from clear to amber, and emitted moderate amounts of smoke and small amounts of soot. Tested to 600$^{o}$F (315$^{o}$C). | | | |

DATA TABLE XXV-E APPENDIX B

LAMINA: SYLGARD 184/CONATHANE EN-1554/184 SYLGARD
(5: S/C/S)

WSTF # 71-2447
MSC # 2962

FLASH AND FIRE POINT TEMPERATURE TEST

| | TEST NUMBER | | | AVERAGE |
|---|---|---|---|---|
| | 1 | 2 | 3 | |
| Test Atmosphere | Oxygen | Same | Same | Oxygen |
| Test Pressure (psia) | 6.2 | Same | Same | 6.2 |
| Sample Weight (gms) | 0.504 | 0.500 | 0.496 | 0.500 |
| Flash Point ($^{o}$F)/ ($^{o}$C) | None | None | None | None |
| Fire Point ($^{o}$F)/ ($^{o}$C) | None | None | None | None |
| OBSERVATIONS/COMMENTS: | The samples partly melted, discolored from clear to amber, and emitted small amounts of smoke. Tested to 600$^{o}$F (315$^{o}$C) | | | |

DATA TABLE XXVI-A

APPENDIX B

CONATHANE EN-1554 FILM WITH 10% FYROL FR-2

(1:C-F)

| ODOR TEST | | | | | |
|---|---|---|---|---|---|
| Material Per Liter Test Chamber Volume 5.083 grms | Sample Withdrawn at Amb.Psi Pressure | Odor Sample Concentration | | | REMARKS |
| | | 1 Part to 29 Parts $0_2$ | 1 Part to 9 Parts $0_2$ | No Dilution | |
| Total Score-Odor Pool Evaluation | | 0.2 | 0.2 | 1.3 | Scores reported are ave. of ten member panel |

DATA TABLE XXVI-B

CONATHANE EN-1554 FILM (2:C)

| ODOR TEST | | | | | |
|---|---|---|---|---|---|
| Material Per Liter Test Chamber Volume 5.061 grms | Sample Withdrawn at Amb.Psi Pressure | Odor Sample Concentration | | | REMARKS |
| | | 1 Part to 29 Parts $0_2$ | 1 Part to 9 Parts $0_2$ | No Dilution | |
| Total Score-Odor Pool Evaluation | | 0.1 | 0.1 | 1.1 | Scores reported are ave. of ten member panel. |

DATA TABLE XXVI-C

SYLGARD 184 - SILICONE FILM (3:S)

| ODOR TEST | | | | | |
|---|---|---|---|---|---|
| Material Per Liter Test Chamber Volume 5.027 grms | Sample Withdrawn at Amb.Psi Pressure | Odor Sample Concentration | | | REMARKS |
| | | 1 Part to 29 Parts $0_2$ | 1 Part to 9 Parts $0_2$ | No Dilution | |
| Total Score-Odor Pool Evaluation | | 0.2 | 0.3 | 0.9 | Scores reported are ave. of ten member panel |

DATA TABLE XXVI-D APPENDIX B

LAMINA: SYLGARD 184/CONATHANE-EN-1554 FILM WITH 10% FYROL FR-2/SYLGARD 184

(4:S/C-F/S)

| Material Per Liter Test Chamber Volume 5.039 grms | ODOR TEST | | | | Remarks: Scores reported are average of ten member panel |
|---|---|---|---|---|---|
| | Sample Withdrawn at Amb. Psi Pressure | 1 part to 29 parts $0_2$ | 1 part to 9 parts $0_2$ | No Dilution | |
| Total Score-Odor Pool Evaluation | | 0.1 | 0.2 | 0.9 | |

DATA TABLE XXVI-E

LAMINA: SYLGARD 184/CONATHANE EN-1554 FILM/SYLGARD 184

(5: S/C/S)

| Material Per Liter Test Chamber Volume 5.128 grms | ODOR TEST | | | | Remarks: Scores reported are average of ten member panel. |
|---|---|---|---|---|---|
| | Sample Withdrawn at Amb. Psi Pressure | 1 part to 29 parts $0_2$ | 1 part to 9 parts $0_2$ | No Dilution | |
| Total Score-Odor Pool Evaluation | | 0.1 | 0.2 | 1.2 | |

DATA TABLE XXVII-A

APPENDIX B

CONATHANE EN-1554 FILM WITH 10% FYROL FR-2

(1:C-F)

| Carbon Monoxide and Total Organics | | | Remarks: |
|---|---|---|---|
| Material Sample Weight<br>20.0316 grms | Weight Loss<br>0.0011 grms/grm | Carbon Monoxide<br>0.6 ugm/gm | Ten meter infrared scan revealed nothing |
| Total Organics (Time) Hours:<br>72 | 0.9 ugm/gm | Sample Withdrawn at 5.0 Psi Chamber Pressure | |

DATA TABLE XXVII-B

CONATHANE EN-1554 FILM (2:C)

| Carbon Monoxide and Total Organics | | | Remarks: |
|---|---|---|---|
| Material Sample Weight<br>20.0553 grms | Weight Loss<br>0.0015 grms/grm | Carbon Monoxide<br>0.4 ugm/gm | Ten meter infrared and GC-MS scans revealed $<$10 ugm/gm methane |
| Total Organics (Time) Hours:<br>72 | 2.4 ugm/gm | Sample Withdrawn at 5.0 Psi Chamber Pressure | |

DATA TABLE XXVII-C

SYLGARD 184 - SILICONE FILM

(3:S)

| Carbon Monoxide and Total Organics | | | Remarks: |
|---|---|---|---|
| Material Sample Weight<br>20.0242 grms | Weight Loss<br>0.0001 grms/grm | Carbon Monoxide<br>0.5 ugm/gm | Ten meter infrared scan revealed 10 ugm/gm methane and benzene |
| Total Organics (Time) Hours:<br>72 | 5.1 ugm/gm | Sample Withdrawn at 5.0 Psi Chamber Pressure | |

DATA TABLE XXVII-D

LAMINA: SYLGARD 184/CONATHANE EN-1554 WITH 10% FYROL FR-2/SYLGARD 184 (4:S/C-F/S)

| Carbon Monoxide and Total Organics | | | |
|---|---|---|---|
| Material Sample Weight<br>20.0446 grms | Weight Loss<br>0.0009 grms/grm | Carbon Monoxide<br>0.7 ugm/gm | Remarks:<br>Ten meter infrared and GC-MS scans revealed < 10 ugm/gm 2-ethoxyethyl acetate and methane |
| Total Organics (Time) Hours: 72 | 2.4 ugm/gm | Sample Withdrawn at<br>5.0 | |

DATA TABLE XXVII-E

LAMINA: SYLGARD 184/CONATHANE EN-1554/SYLGARD 184 (5:S/C/S)

| Carbon Monoxide and Total Organics | | | |
|---|---|---|---|
| Material Sample Weight<br>20.0265 grms | Weight Loss<br>0.0006 grms/grm | Carbon Monoxide<br>0.3 ugm/gm | Remarks:<br>Ten meter infrared scan revealed nothing |
| Total Organics (Time) Hours:<br>72 | 1.5 ugm/gm | Sample Withdrawn at<br>5.0<br>Psi Chamber Pressure | |

THERMOGRAPH DATA TABLE XXVIII

APPENDIX B

| | 1:C-F | 2:C | 3:S | 4:S/C-F/S | 5:S/C/S |
|---|---|---|---|---|---|
| Thermograph Data | Conathane EN-1554 Film with 10% Fyrol FR-2 | Conathane EN-1554 Film | Sylgard 184 Silicone Film | Laminate: Sylgard 184/ Conathane-EN-1554 Film with 10% Fyrol FR-2/Sylgard 184 | Lamina: Sylgard 184/ Conathane EN-1554/ Sylgard 184 |
| WSTF # | 71-2450 | 71-2451 | 71-2449 | 71-2448 | 71-2447 |
| MSC # | 2965 | 2966 | 2964 | 2963 | 2962 |
| Sample Form | Sheet | Sheet | Sheet | Sheet | Sheet |
| Sample Geometry | 2"x3/8" strips | 7 mm dia. discs | 7 mm dia. discs | 7 mm dia. discs | 7 mm dia. discs |
| Test Atmosphere | Oxygen | Oxygen | Oxygen | Oxygen | Oxygen |
| Test Pressure, Torr | 320 | 320 | 320 | 320 | 320 |
| Initial Sample Weight, mg. | 233.3 | 132.6 | 136.1 | 157.0 | 148.1 |
| Weight Loss, mg. | 35.5 | 6.7 | 0.3 | 7.2 | 3.3 |
| Weight Loss, % | 15.2 | 5.1 | - | 4.6 | 2.2 |
| Heating Rate, $^{o}$C/min | 10 | 10 | 10 | 10 | 10 |
| Temp. Max. Wt. Chg, $^{o}$C | >315 | >315 | >315 | >315 | >315 |
| Temp. of Max. Exotherm $^{o}$C | >315 | None | >315 | None | None |
| Temp. of Max. Endotherm $^{o}$C | 245 | 240 | None | 230 | None |
| Temp. of Initial Wt. Loss $^{o}$C | 190 | 230 | 300 | 230 | 260 |
| Temp. of Initial Decomp., $^{o}$C | 210 | 280 | None | 270 | None |

THERMOGRAPH DATA TABLE XXVIII

(continued)

| Thermograph Data | 1:C-F | 2:C | 3:S | 4:S/C-F/S | 5:S/C/S |
|---|---|---|---|---|---|
| Temp. Max. of Test, °C | 315 | 315 | 315 | 315 | 315 |
| Crucible: | | | | | |
| Material | Pt. | Pt. | Pt. | Pt. | Pt. |
| Size, mm | 7 | 7 | 7 | 7 | 7 |
| Shape | | | | | |
| Effluent - Gas Analysis | None | None | None | None | None |
| Thermograph Copy # (See Appendix C) | 10 | 11 | 12 | 13 | 14 |

THERMOGRAPH DATA TABLE XXVIII (continued)

| | |
|---|---|
| OBSERVATIONS: | Conathane EN-1554 Film With 10% Fyrol FR-2 (1:C-F)<br>At approximately 170°C the sample started to melt; at 210°C the sample was degassing slowly. The sample was charring and degassing violently at 270°C; the sample began to flow and degass over the sides of the crucible at 310°C. At the termination of test soft slightly gummy brown film covered the inside and outside of crucible. |
| | Conathane EN-1554 Film (2:C)<br>At approximately 220°C the sample started to melt; at 250°C the sample was degassing, and at 270°C the sample was charring. A gummy brown mass was left in the bottom of the crucible at the termination of the test. |
| | Sylgard 184 - Silicone Film (3:S)<br>No apparent change in sample. |
| | Lamina: Sylgard 184/Conathane EN-1554 With 10% Fyrol FR-2/Sylgard 184 (4:S/C-F/S)<br>At approximately 270°C the sample began charring. At the termination of the test, the center layer of the 3-piece laminate had dissolved, flowed and charred. The outer two layers did not seem greatly affected. |
| | Lamina: Sylgard 184/Conathane EN-1554/Sylgard 184 (S/C/S)<br>At the termination of test the sample was partially fused, very soft and gummy, and slightly charred. |

## APPENDIX B

## DATA TABLE XXIX

## DIMENSIONAL CHANGES UNDER PRESSURE FOR PHASE I WINDOWS

| Window No. | Axial Wire Angle (degrees) | Length (cm) | | | | Diameter (cm) | | | | Percent Changes | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Under Pressure (nscm) | | | | Under pressure psig (nscm) | | | 3.471 | | 6.943 | | 10.413 | |
| | | Original | 3.471 | 6.943 | 10.413 | Original | 3.471 | 6.943 | 10.413 | L | D | L | D | L | D |
| US-10 | 0 | 24.20 | 24.20 | 24.20 | 24.20 | 15.90 | 15.90 | 15.90 | 15.90 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | 24.55 | 24.60 | 24.60 | 24.60 | 15.95 | 15.95 | 15.95 | 16.00 | .203 | 0 | .203 | 0 | .204 | .322 |
| | | 24.50 | 24.55 | 24.55 | 24.60 | 15.90 | 15.90 | 15.90 | 15.95 | .204 | 0 | .204 | 0 | .408 | .314 |
| US-19 | 0 | 24.20 | 24.30 | 24.30 | 24.30 | 15.80 | 15.90 | 15.90 | 15.90 | .413 | .633 | .413 | .633 | .413 | .633 |
| | | 24.40 | 24.50 | 24.50 | 24.50 | 15.70 | 15.70 | 15.80 | 15.80 | .410 | 0 | .410 | .637 | .410 | .637 |
| | | 24.30 | 24.30 | 24.40 | 24.40 | 15.60 | 15.75 | 15.80 | 15.80 | 0 | .962 | .411 | 1.28 | .411 | 1.282 |
| US-17 | 7 | 24.50 | 24.50 | 24.55 | 24.55 | 15.90 | 15.90 | 15.90 | 15.90 | 0 | 0 | .204 | 0 | .204 | 0 |
| | | 24.80 | 24.85 | 24.90 | 24.90 | 15.90 | 15.90 | 15.90 | 15.90 | .202 | 0 | .403 | 0 | .403 | 0 |
| | | 24.60 | 24.60 | 24.70 | 24.70 | 15.75 | 15.75 | 15.80 | 15.80 | 0 | 0 | .407 | .317 | .407 | .317 |
| US-20 | 15 | 24.20 | 24.30 | 24.30 | 24.30 | 15.80 | 15.90 | 15.90 | 15.90 | .413 | .633 | .413 | .633 | .413 | .633 |
| | | 24.40 | 24.50 | 24.50 | 24.50 | 15.70 | 15.70 | 15.80 | 15.80 | .410 | 0 | .410 | .637 | .410 | .637 |
| | | 24.30 | 24.30 | 24.60 | 24.40 | 15.60 | 15.75 | 15.85 | 15.85 | 0 | .962 | .412 | 1.602 | .412 | 1.602 |

APPENDIX B

DATA TABLE XXX

DIMENSIONAL CHANGES AND MATERIAL DEGRADATION DUE TO COLLAPSE/EXTENSION CYCLES FOR PHASE I WINDOWS

| Window No. | Axial Wire Angle | Orig. Length (cm) | Collap Length (cm) | Length after cycling | | | After * Hrs. in Collap. State | Diameter after cycling | | | | After * Hrs in Collap. Cond. | Starting Torque (in-lb) Range for Collapse | | | After* Hours Collapse | MATERIAL DEGRADATION | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 cycle | 5 cycles | 10 cycles | | Orig. | 1 cycle | 5 cycles | 10 cycles | | | | | | After 10 Cycles of Collapse/Extension | | | After 24 Hours in Collapsed Condition | | |
| | | | | | | | | | | | | | Orig. | 1 cycle | 5 cycles | 10 cycles | Delamination | Crack | Run Mark | Delamination | Crack | Run Mark |
| US-10 | 0° | 24.40 | 7.10 | 24.40 | 24.40 | 24.40 | 24.40 | 15.85 | 15.85 | 15.75 | 15.80 | 15.70 | 140 to 75 | 75 to 60 | 65-40 | 60 | 45-25 | Slightly* delamination of silicone near fittings | No* | No* | Silicone* delaminated at two spots near fitting | No* | One* run mark |
| | | 24.45 | 7.60 | 24.45 | 24.45 | 24.40 | 24.40 | 15.80 | 15.70 | 15.70 | 15.65 | 15.40 | | | | | | | | | | |
| | | 24.40 | 6.75 | 24.40 | 24.40 | 24.45 | 24.35 | 15.90 | 15.85 | 15.90 | 15.70 | 15.75 | | | | | | | | | | |
| US-17 | 7° | 24.50 | 9.60 | 24.50 | 24.50 | 24.50 | 24.50 | 15.90 | 15.80 | - | 15.80 | ** 15.70 | 170 to 110 | 110-60 | - | - | 90-40 | No | Silicone crack near fitting | No | Slight delamination at the joint and near the base | Crack at the film joint | Three run marks in silicone |
| | | 24.80 | 10.50 | 24.80 | 24.80 | 24.75 | 24.80 | 15.75 | 15.70 | - | 16.00 | 15.70 | | | | | | | | | | |
| | | 24.60 | 9.30 | 24.60 | 24.60 | 24.60 | 24.60 | 15.90 | 15.90 | - | 15.90 | 15.80 | | | | | | | | | | |
| US-20 | 15° | 24.20 | 8.50 | 24.20 | 24.20 | 24.20 | 24.20 | 15.80 | 15.75 | 15.70 | 15.70 | ** 15.40 | 170-80 | 120-80 | 90-50 | - | 65-35 | Outer layer at one spot became cloudy No visible delamination | No | One Run Mark | Slight delamination of silicone in the bottom portion | Cracks in outer layer | Two run marks- Deformed at 2 places |
| | | 24.85 | 7.60 | 24.80 | 24.80 | 24.75 | 24.70 | 15.80 | 15.80 | 15.70 | 15.80 | 15.40 | | | | | | | | | | |
| | | 24.90 | 8.70 | 24.85 | 24.90 | 24.95 | 24.70 | 15.85 | 15.80 | 15.75 | 15.70 | 15.70 | | | | | | | | | | |

* Window was held in collapsed condition for 40 hours and then released. Measurements were taken after 20 minutes.

** Window held for 24 hours in collapsed condition and then released. Measurements were taken after 20 minutes.

# APPENDIX C

The following graphs contain the complete light transmittance curves (recorded on General Electric Spectrophotometer) and Thermographs.

Superimposed on each light transmittance graph are the curves for one construction and corresponding control specimens after exposure to the environmental conditons as indicated.

Each thermograph contains Gen. TGA, Exp. TGA, DTG, DTA, and T°C curves.

Each graph is referenced to a table previously referred to in this report.

Graphs No. 1 through 3 - Reference Table I

Graphs No. 4 through 9 - Reference Tables III and XXII

Graphs No. 10 through 14 - Reference Tables III and XXVIII (Thermographs)

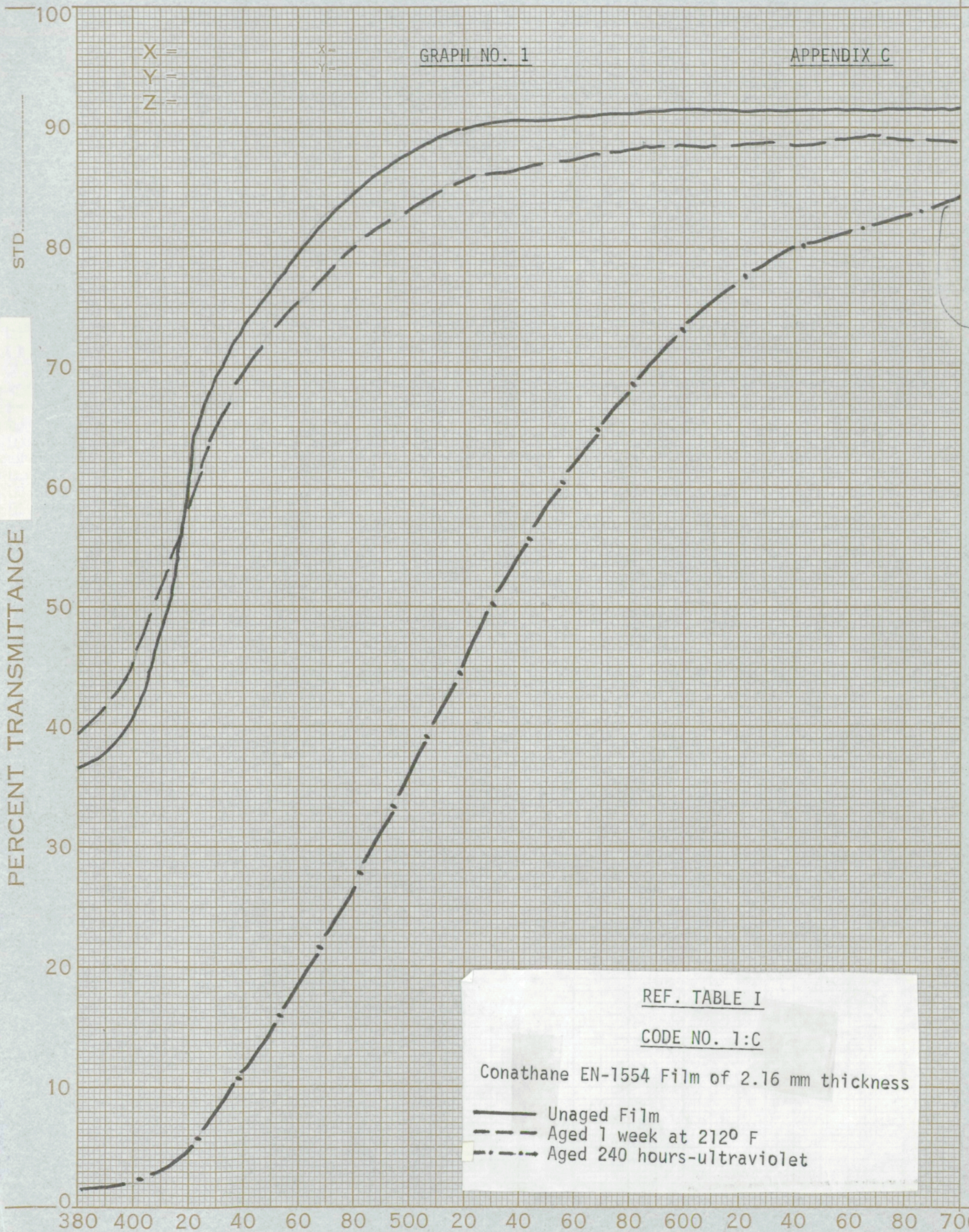
GENERAL ELECTRIC RECORDING SPECTROPHOTOMETER

X =
Y =
Z =

X=
Y=

GRAPH NO. 1

APPENDIX C




REF. TABLE I

CODE NO. 1:C

Conathane EN-1554 Film of 2.16 mm thickness

——— Unaged Film
– – – Aged 1 week at 212° F
–·–·– Aged 240 hours-ultraviolet

STD.

DATE

BY

TEST NO.

INST. NO.

N.P. 159839

GRAPH NO. 2

APPENDIX C

X =
Y
Z =

X=
Y=

STD

DATE

BY

TEST NO.

INST. NO.

N.P. 159839

PERCENT TRANSMITTANCE

100
90
80
70
60
50
40
30
20
10
0

380 400 20 40 60 80 500 20 40 60 80 600 20 40 60 80 700

WAVELENGTH IN MILLIMICRONS

REF. TABLE I

CODE NO. 3:S

Sylgard 184 Film of 2.42 mm Thickness

——— Unaged Film
– – – Aged 1 week at 212° F
—·—· Aged 240 hours-ultraviolet

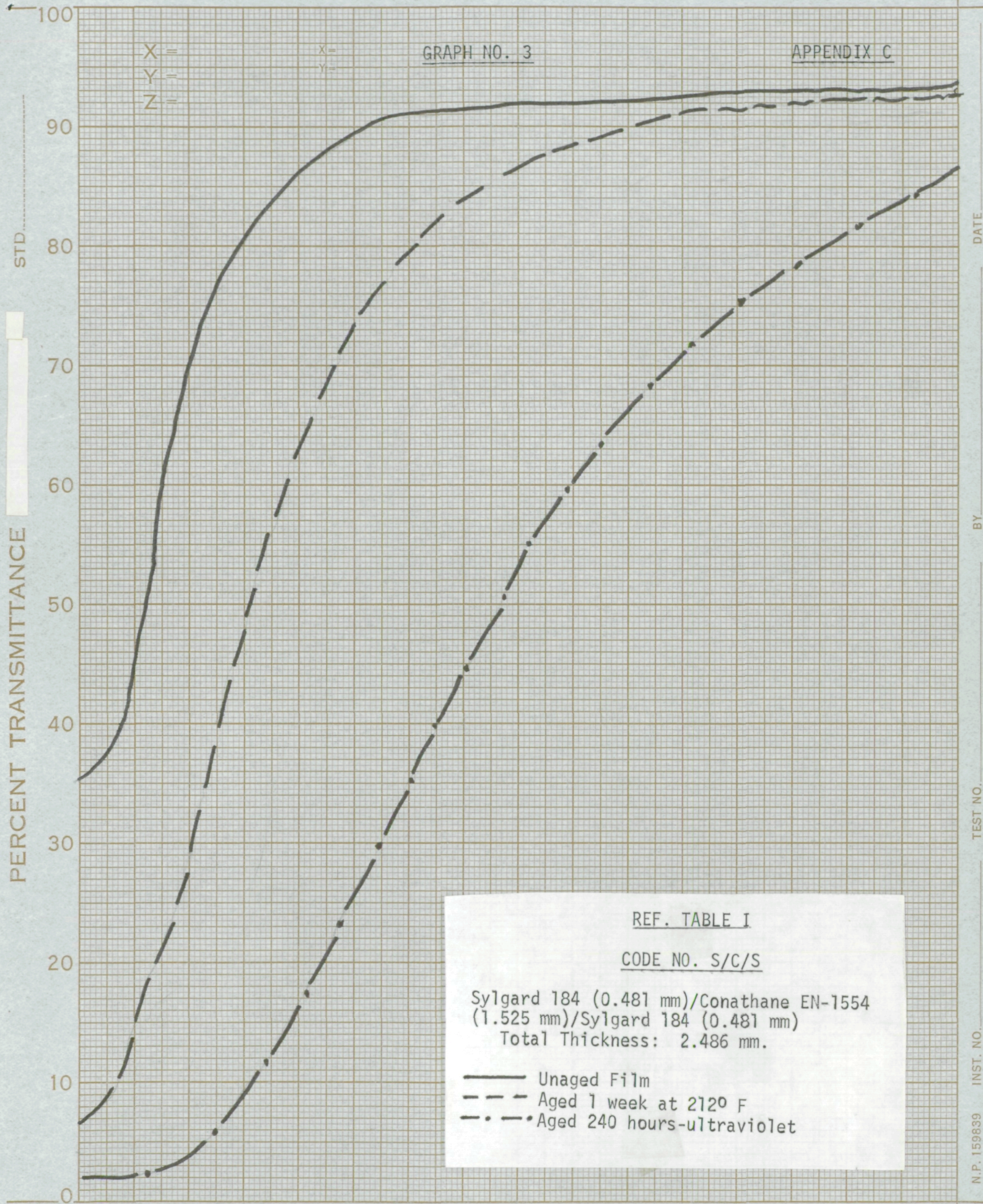
GENERAL ELECTRIC RECORDING SPECTROPHOTOMETER

X =
Y =
Z =

X=
Y=

GRAPH NO. 3

APPENDIX C




REF. TABLE I

CODE NO. S/C/S

Sylgard 184 (0.481 mm)/Conathane EN-1554 (1.525 mm)/Sylgard 184 (0.481 mm)
Total Thickness: 2.486 mm.

——— Unaged Film
– – – Aged 1 week at 212° F
—·—· Aged 240 hours-ultraviolet

STD

DATE

BY

TEST NO.

INST. NO.

N.P. 159839

GRAPH NO. 4

APPENDIX C

X =
Y =
Z =

X=
Y=

STD.

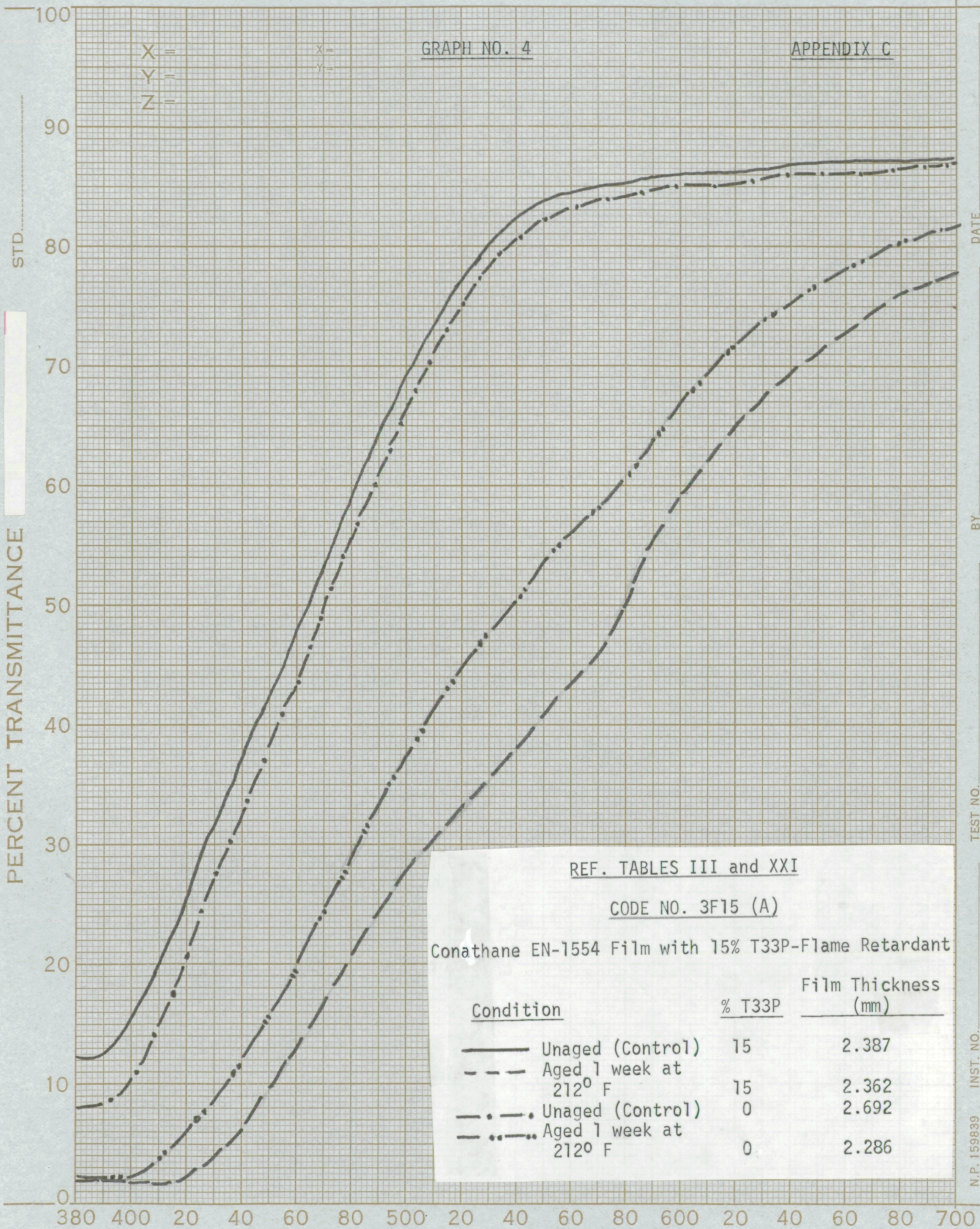
DATE

BY

TEST NO.

INST. NO.

N.P. 159839




REF. TABLES III and XXI

CODE NO. 3F15 (A)

Conathane EN-1554 Film with 15% T33P-Flame Retardant

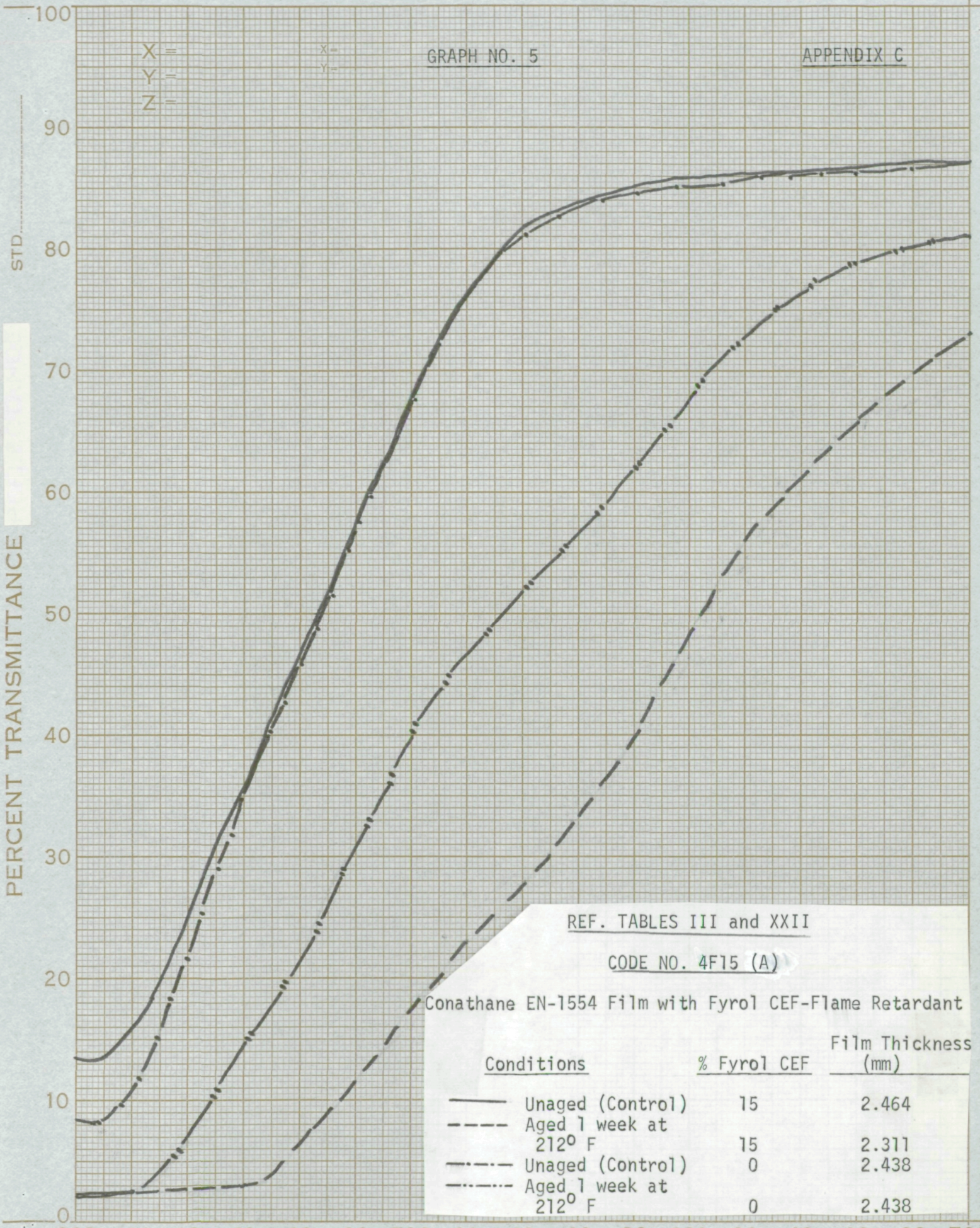
| Condition | % T33P | Film Thickness (mm) |
|---|---|---|
| ——— Unaged (Control) | 15 | 2.387 |
| – – – Aged 1 week at 212° F | 15 | 2.362 |
| —·— Unaged (Control) | 0 | 2.692 |
| —··— Aged 1 week at 212° F | 0 | 2.286 |

X =
Y =
Z =

X=
Y=

GRAPH NO. 5

APPENDIX C




REF. TABLES III and XXII

CODE NO. 4F15 (A)

Conathane EN-1554 Film with Fyrol CEF-Flame Retardant

| Conditions | % Fyrol CEF | Film Thickness (mm) |
|---|---|---|
| ——— Unaged (Control) | 15 | 2.464 |
| - - - - Aged 1 week at 212° F | 15 | 2.311 |
| —·—·— Unaged (Control) | 0 | 2.438 |
| —··—··— Aged 1 week at 212° F | 0 | 2.438 |

STD.

DATE

BY

TEST NO.

INST. NO.

N.P. 159839

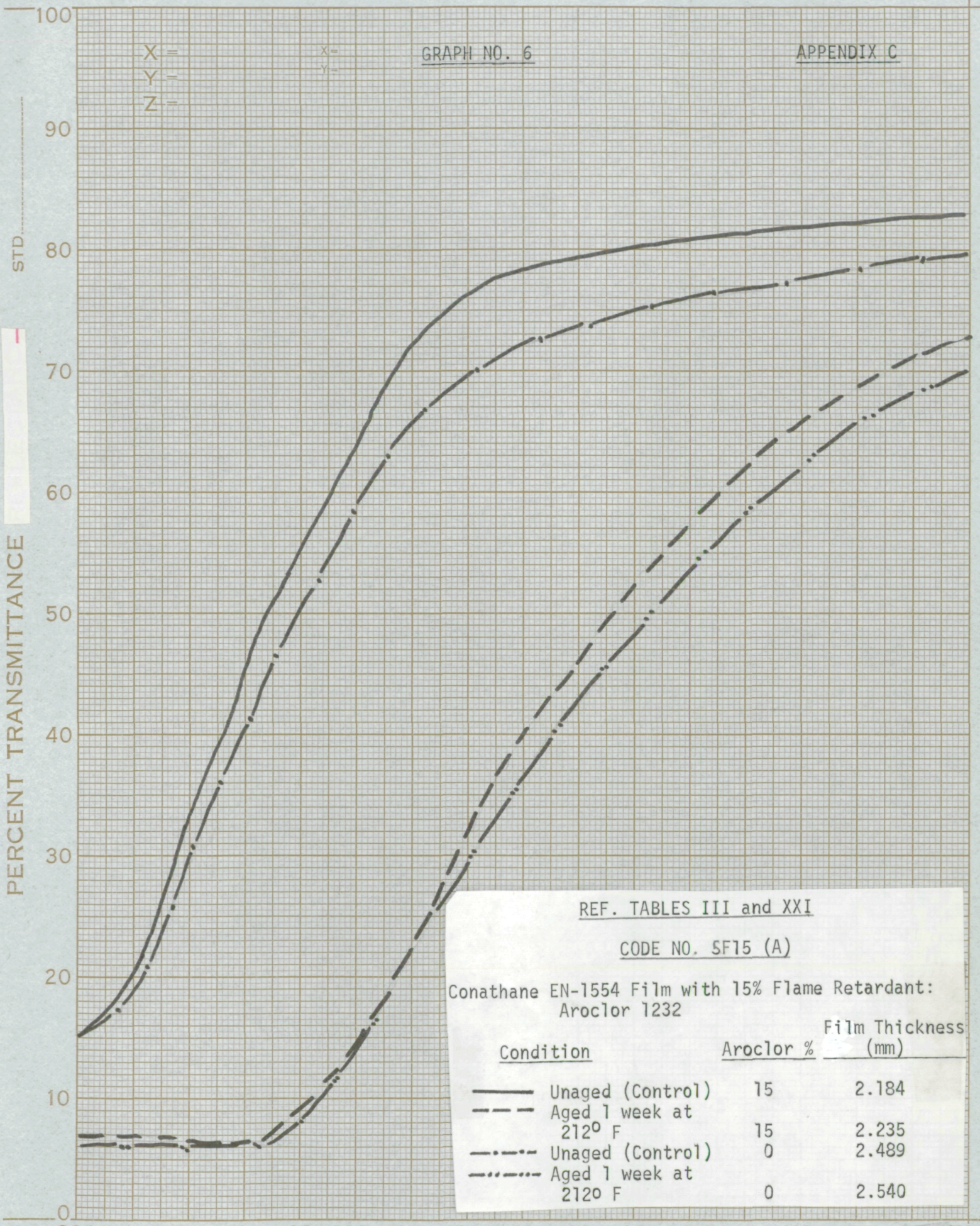
GENERAL ELECTRIC RECORDING SPECTROPHOTOMETER

X =
Y =
Z =

X= Y=

GRAPH NO. 6

APPENDIX C




REF. TABLES III and XXI

CODE NO. 5F15 (A)

Conathane EN-1554 Film with 15% Flame Retardant: Aroclor 1232

| Condition | Aroclor % | Film Thickness (mm) |
|---|---|---|
| ——— Unaged (Control) | 15 | 2.184 |
| – – – Aged 1 week at 212° F | 15 | 2.235 |
| —·—·— Unaged (Control) | 0 | 2.489 |
| —··—··— Aged 1 week at 212° F | 0 | 2.540 |

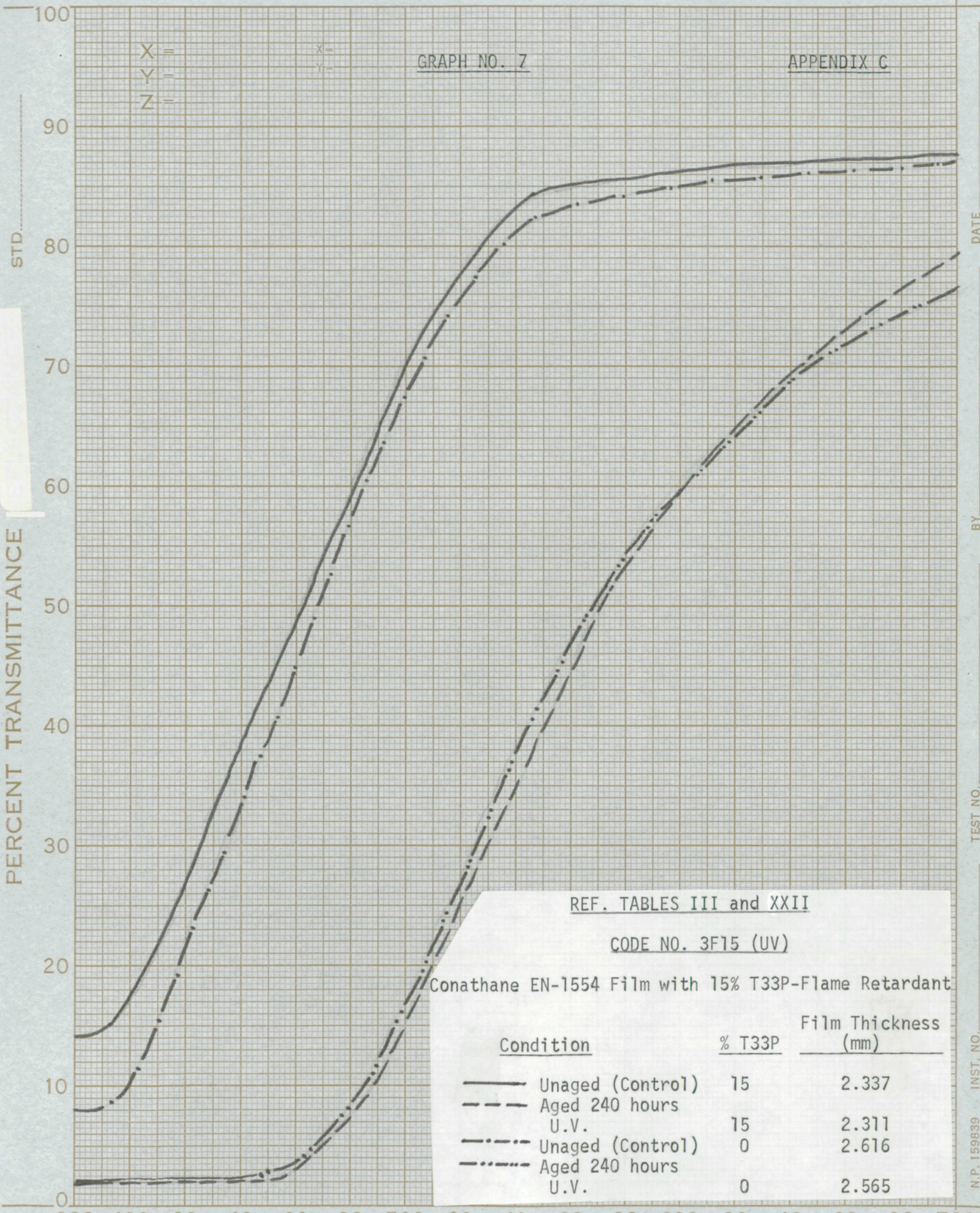
STD. DATE BY TEST NO. INST. NO. N.P. 159839

X =
Y =
Z =

X=
Y=

GRAPH NO. 7

APPENDIX C




REF. TABLES III and XXII

CODE NO. 3F15 (UV)

Conathane EN-1554 Film with 15% T33P-Flame Retardant

| Condition | % T33P | Film Thickness (mm) |
|---|---|---|
| Unaged (Control) | 15 | 2.337 |
| Aged 240 hours U.V. | 15 | 2.311 |
| Unaged (Control) | 0 | 2.616 |
| Aged 240 hours U.V. | 0 | 2.565 |

STD.

DATE

BY

TEST NO.

INST. NO.

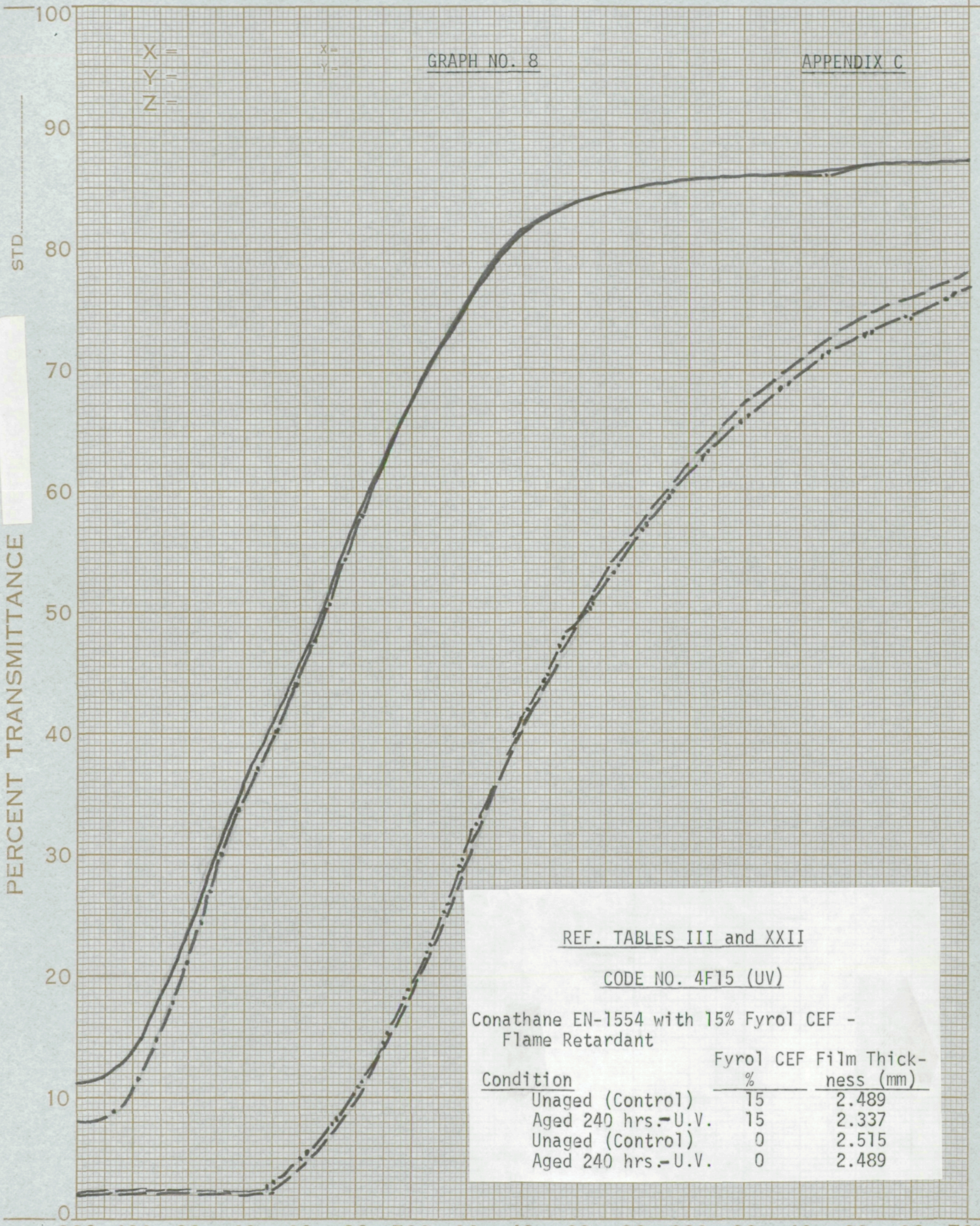
N.P. 159839

X =
Y =
Z =

X =
Y =

GRAPH NO. 8

APPENDIX C




REF. TABLES III and XXII

CODE NO. 4F15 (UV)

Conathane EN-1554 with 15% Fyrol CEF - Flame Retardant

| Condition | Fyrol CEF % | Film Thickness (mm) |
|---|---|---|
| Unaged (Control) | 15 | 2.489 |
| Aged 240 hrs.-U.V. | 15 | 2.337 |
| Unaged (Control) | 0 | 2.515 |
| Aged 240 hrs.-U.V. | 0 | 2.489 |

STD

DATE

BY

TEST NO.

INST. NO.

N.P. 159839

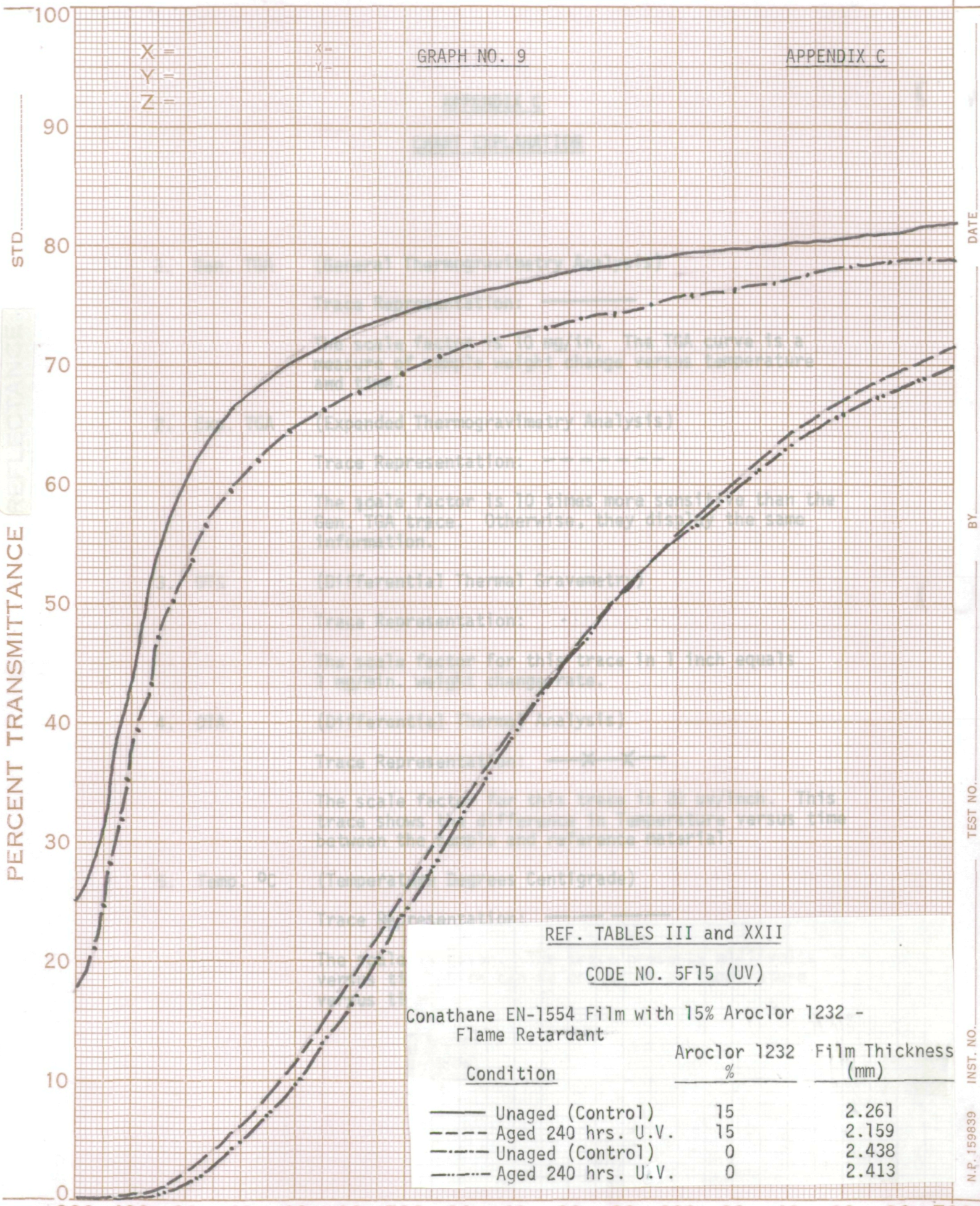
GENERAL ELECTRIC RECORDING SPECTROPHOTOMETER

X =
Y =
Z =

X=
Y=

GRAPH NO. 9

APPENDIX C




REF. TABLES III and XXII

CODE NO. 5F15 (UV)

Conathane EN-1554 Film with 15% Aroclor 1232 - Flame Retardant

| Condition | Aroclor 1232 % | Film Thickness (mm) |
|---|---|---|
| ——— Unaged (Control) | 15 | 2.261 |
| - - - - Aged 240 hrs. U.V. | 15 | 2.159 |
| —·—·— Unaged (Control) | 0 | 2.438 |
| —··—··— Aged 240 hrs. U.V. | 0 | 2.413 |

STD.

DATE

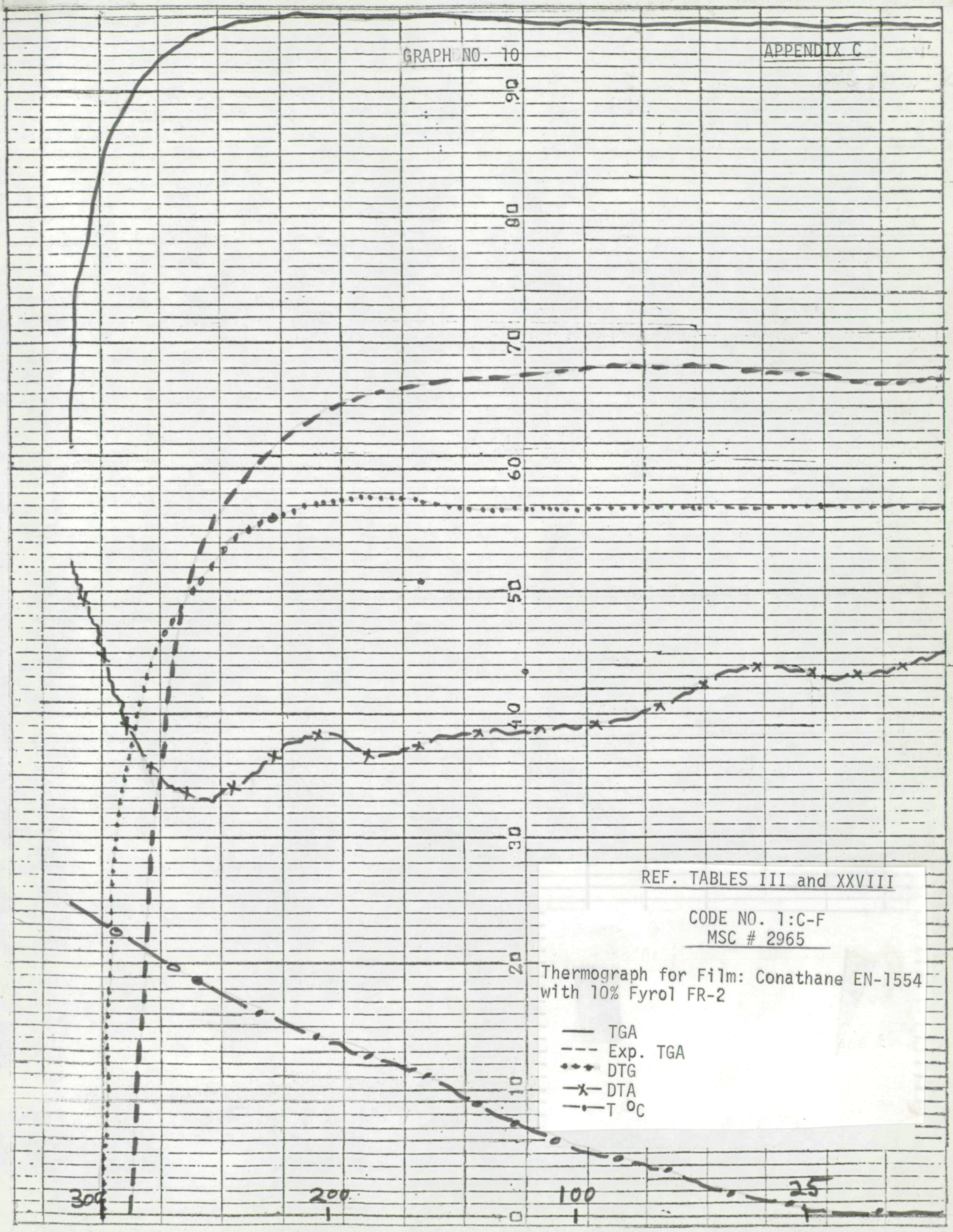
BY

TEST NO.

INST. NO.

N.P. 159839

GRAPH NO. 10



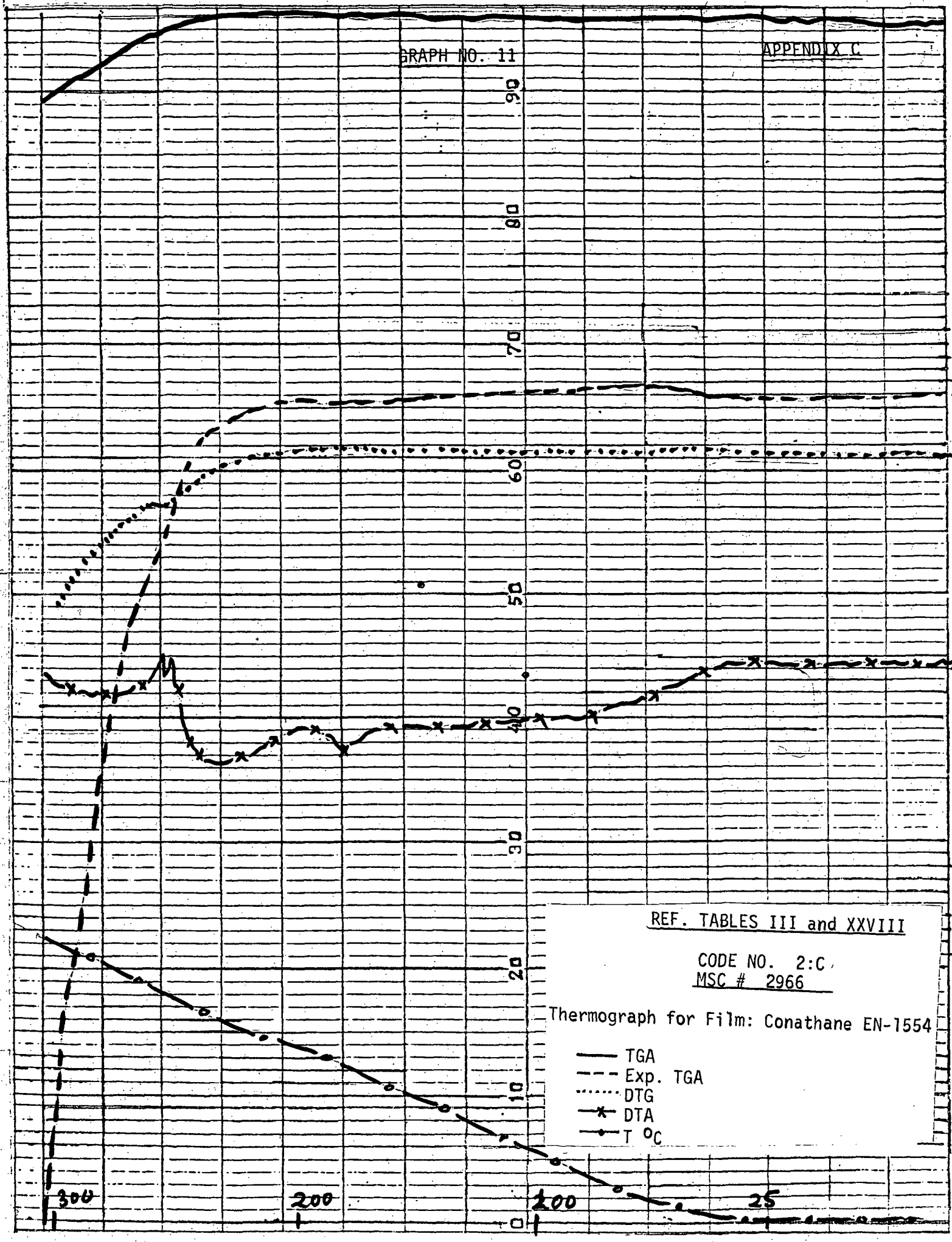

REF. TABLES III and XXVIII

CODE NO. 1:C-F
MSC # 2965

Thermograph for Film: Conathane EN-1554 with 10% Fyrol FR-2

— TGA
– – – Exp. TGA
•••• DTG
—x— DTA
—•— T °C

GRAPH NO. 11



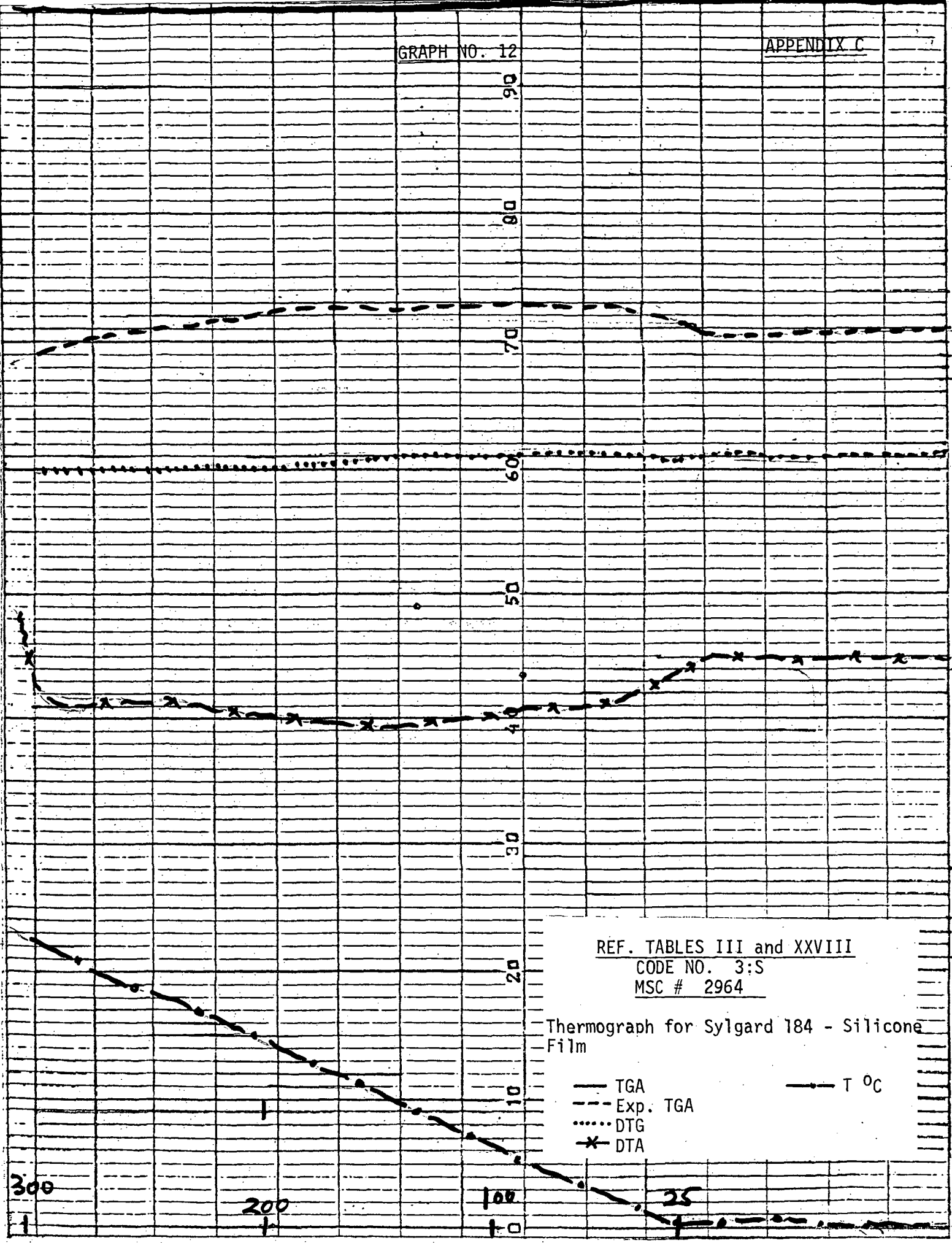

REF. TABLES III and XXVIII

CODE NO. 2:C
MSC # 2966

Thermograph for Film: Conathane EN-1554

— TGA
– – – Exp. TGA
····· DTG
—x— DTA
—•— T °C

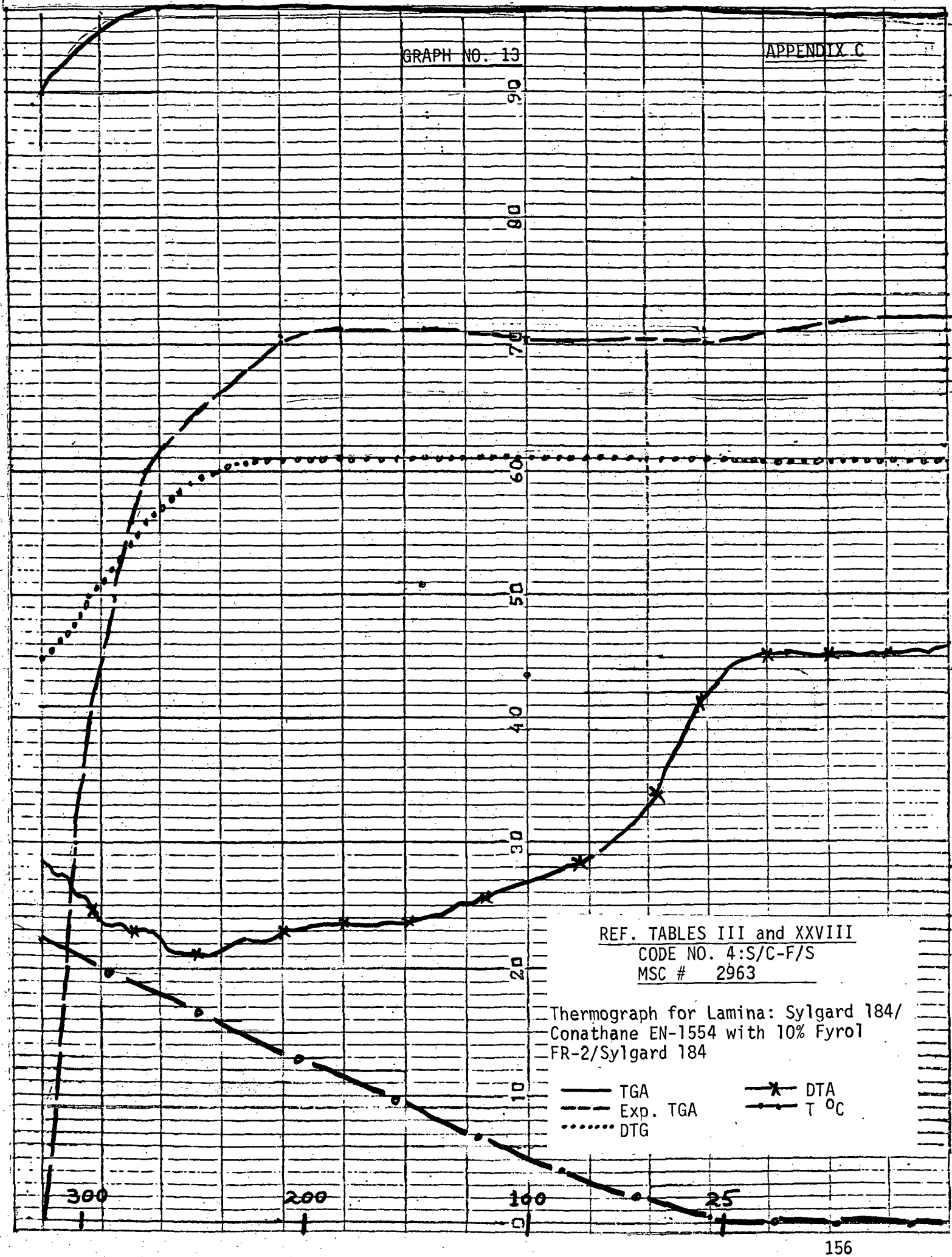
GRAPH NO. 12




REF. TABLES III and XXVIII
CODE NO. 3:S
MSC # 2964

Thermograph for Sylgard 184 - Silicone Film

— TGA
--- Exp. TGA
····· DTG
-x- DTA
—•— T °C

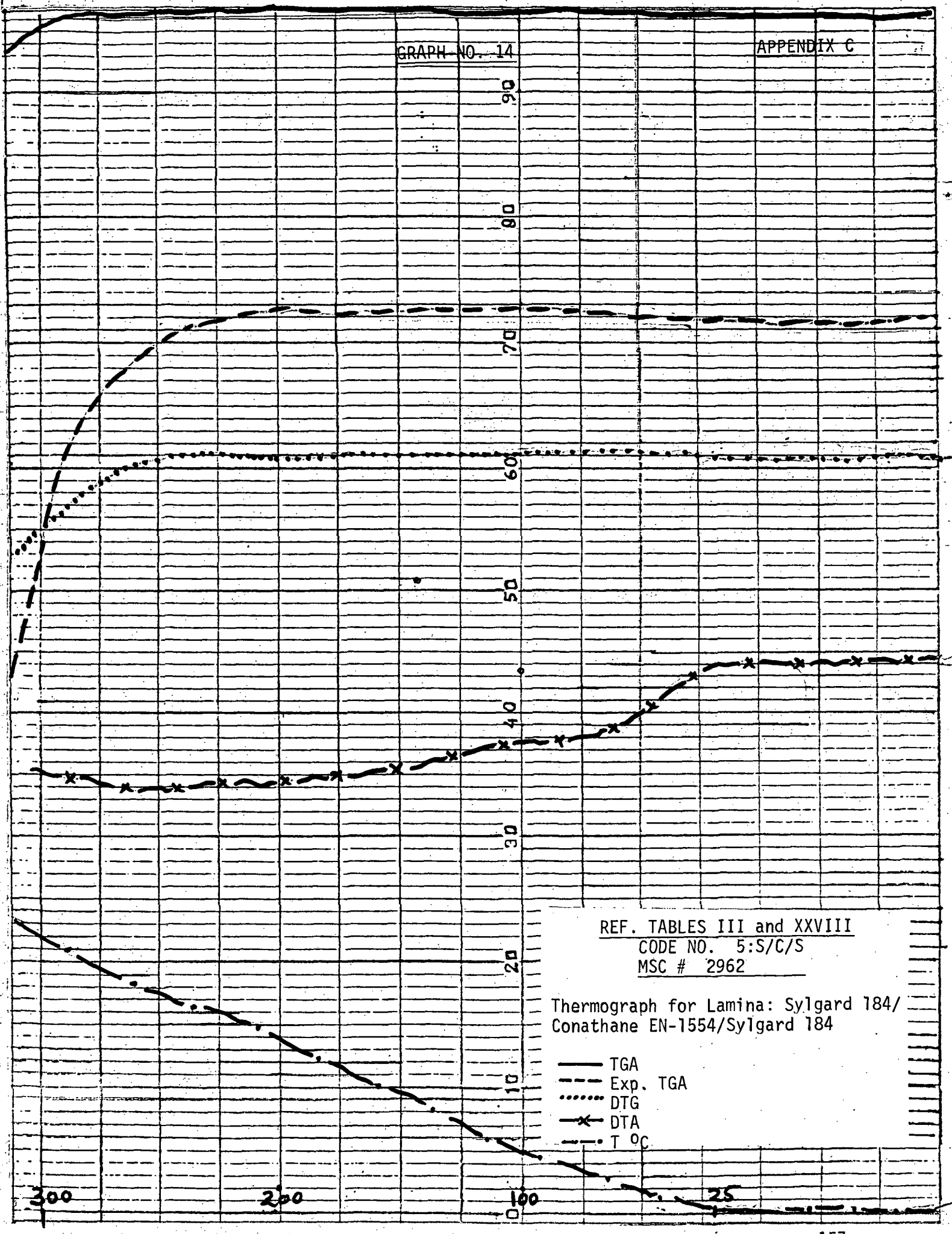



REF. TABLES III and XXVIII
CODE NO. 4:S/C-F/S
MSC # 2963

Thermograph for Lamina: Sylgard 184/ Conathane EN-1554 with 10% Fyrol FR-2/Sylgard 184

TGA
Exp. TGA
DTG
DTA
T $^{o}$C

GRAPH NO. 14




REF. TABLES III and XXVIII
CODE NO. 5:S/C/S
MSC # 2962

Thermograph for Lamina: Sylgard 184/ Conathane EN-1554/Sylgard 184

— TGA
– – – Exp. TGA
····· DTG
—×— DTA
—·— T °C